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THE DEVELOPMENT OF SYSTEMATIC PETROGRAPHY IN THE NINETEENTH CENTURY.

Part II.[1]

Beginning of the microscopical era.— Having presented the state of systematic petrography up to the time when the polarizing microscope became the instrument of prime importance in the investigation of rocks, we now proceed to the study of the more recent schemes of classification, based upon the larger knowledge. For all systems thus far reviewed, it must be recognized that ignorance of the characters and relationships of many rocks rendered a comprehensive and logical scheme impossible. The frame work of system was necessarily constructed without full knowledge of the applicability of some of the factors employed. With the polarizing microscope and improved methods of chemical analysis this condition has now disappeared, and while the time may not be ripe for unbiased criticism it is plain that modern systems of classification must ultimately be judged with regard to the greater and almost perfect knowledge of the actual characters of rocks enjoyed by the authors of those systems. The responsibility for the choice of factors suitable for the construction of a comprehensive system and for a logical, consequent, and consistent application of those factors clearly increases with knowledge of the objects to be classified.

The microscopical study of rocks, continuing for nearly four

[1] Continued from p. 376.

decades with ever improving facilities and methods, has added a vast store of knowledge concerning the characters of these objects. Revelations concerning the composition of types long known have often been astonishing. The essence of rock structures has been made clear. The uttermost parts of the earth have been searched, and many new and interesting varieties have been discovered—not all in distant fields, but often close at hand. For new structures and new types, new terms have been proposed, and the nomenclature has thus expanded enormously. In the light of new discoveries, old conceptions have given way to new ideas, and the terms expressing them have yielded to new ones, or, in too many cases, the old nomenclature has been retained with new definitions. But while the last third of the nineteenth century may be termed the microscopical period of petrography, great additions to our knowledge of rocks were also made in this period on all older lines of study, and especially by quantitative chemical analysis and by investigations as to the modes of occurrence and the field relations of different rocks.

This review, which deals with system, must trace the application of new or revised principles to classification during this period of rapid addition to knowledge. It is perhaps quite natural that the greater part of the systematic advance was in partially worked out revisions of old schemes—grafting some new idea to the old trunk. It is also natural that the greatest work has been in the field to which the microscope has been particularly applied, so that at times petrography has been treated as though narrowed to the microscopical petrography of igneous rocks.

While the flood of microscopical rock studies was at its height, it was manifestly impossible for anyone to do more than to present the new information in comprehensive form, without finished attempt to apply it to the systematic arrangement of rocks. It is with this condition in mind that the important works upon microscopical petrography, issued in the decade 1870 to 1880, must be judged. Their actual effect upon the systematic science was, however, very great, from the mere fact

that they exerted a controlling influence over the usage of a multitude of workers.

Ferdinand Zirkel, 1873.—In 1873 appeared *Die mikroskopische Beschaffenheit der Mineralien und Gesteine*, by F. Zirkel. The systematic point of view occupied by this authority at this time is expressed in the following tabular analysis of his larger divisions of rocks:

A. Non-clastic rocks ("Nicht-klastische Gesteine").
  I. Simple ("Einfach").
  II. Composite ("Gemengt").
    1. Massive ("Massig").
      a. Feldspathic ("Feldspath-haltig").
      b. Non-feldspathic ("Feldspath-frei").
    2. Schistose ("Schieferig").
B. Clastic-secondary rocks ("Klastische-deuterogene-Gesteine").

Comparing this scheme with that of the *Lehrbuch der Petrographie*, we find that the microscope has convinced Zirkel that *crystalline* cannot be appropriately opposed to *clastic*. He also believes that *original* cannot be used for non-clastic rocks because they have been discovered to be at the present time in part composed of alteration products. He therefore falls back on a negative term, *nonclastic*, admitting that it is indefinite—"misslich." *Massive* is defined as *not schistose, in larger part granular*—"nicht geschiefert, zum grossen Theil körnig."

The work deals mainly with the *feldspathic, massive, composite, non-clastic rocks*. These are subdivided as follows:

I. Orthoclase rocks.
  1. With quartz.
  2. Without quartz, with or without plagioclase.
  3. Without quartz, with nephelite (or leucite).
II. Plagioclase rocks.
  1. With hornblende.
  2. With augite.
  3. With diallage.
  4. With hypersthene.
  5. With mica.
  6. With olivine.
III. Nephelite rocks.
IV. Leucite rocks.

The use of the soda-lime feldspars—oligoclase, labradorite, and anorthite, as factors in the subdivision of feldspathic rocks, found in the *Lehrbuch*, had been shown by the microscope to be an error, and it disappears without comment. The mineral composition of rocks is here applied to their classification in a qualitative way almost exclusively. Zirkel remarks: "To the non-feldspathic, non-schistose, composite rocks belong among others: eclogite, tourmaline rock, olivine rock, eulysite and saussurite-gabbro." Of these only three are described and within a compass of two pages.

The age distinction in classification of igneous rocks is freely characterized by Zirkel as unnatural and undesirable and it is not formally recognized in this work as it was in the *Lehrbuch*, yet he could not see his way to carry out the reform necessary to its rejection and retained in description many of the duplicate terms based on it.

Structure and *crystalline condition* were not given a defined rôle in Zirkel's new system, but in practice the granular, porphyritic, fluidal and glassy forms were distinguished.

A. von Lasaulx, 1875.—The *Elemente der Petrographie*,[1] by A. von Lasaulx, issued in 1875, is another attempt to utilize the results of microscopical study of rocks in their classification and description. Von Lasaulx believed that since there are no true rock species, and since transitions in all directions are most common, classification must consist in the establishment of *types*, about which should be grouped the intermediate kinds of rocks. He announced as his guiding principle that rocks must be classified upon the basis of simple, definitely known and easily recognized, morphological properties. Genetic criteria did not seem to him applicable because always more or less hypothetical and in some cases entirely so. He, therefore, discards the primary classification of rocks on genetic principles, advocated by von Cotta and others, and returns to von Leonhard's elementary division into *Simple*, *Composite* and *Clastic* rocks, omitting the *Apparently simple* class as no longer necessary.

[1] *Elemente der Petrographie*, Bonn, 1875, pp. 486.

The morphological characteristic of rocks chosen by von Lasaulx as most applicable to the systematic subdivision of the classes mentioned was the degree or distinctness of crystallinity, which is surely the most variable of all their properties, and hence least adapted to the formation of well-defined groups. The major divisions formed by von Lasaulx are as follows:

Simple Rocks:

A. Non-crystalline (amorphous) or semi-crystalline.
B. Crystalline granular.
   a. Really simple.
   b. Rocks forming transitions to Composite group through the appearance of vicarious constituents (*e.g.*, amphibolite, serpentine, etc.).

Composite Rocks:

A. Massive.
   a. Amorphous, glassy (obsidian, etc.).
   b. Semi-crystalline (including vitrophyres).
   c. Crystalline.
      1. With abundant glassy base (basalt, etc.).
      2. With microaphanitic more or less individualized groundmass.
         aa. Groundmass alone (felsite, etc.).
         bb. True porphyries (felsite-porphyry, etc.).
      3. Rocks which are almost completely crystalline, mainly pseudo-porphyritic, etc. (phonolite, hornblende-andesite, etc.).
      4. Crystalline granular.
         aa. Feldspathic (granite, etc.).
         bb. Non-feldspathic (Greisen, eclogite, etc.).
B. Stratified Rocks:
   a. Feldspathic (gneiss, etc.).
   b. Non-feldspathic (mica-schist, etc.).

Clastic Rocks:

A. Semi-clastic (clay slate, kaolin, tuff, etc.).
B. Purely clastic.

Mineral composition is applied as a factor to produce the commonly recognized rock types within these groups. It will be noted that many of the divisions above mentioned are not only quite indefinite but they are, also, inconsequent. Thus, three out of four divisions of *crystalline massive* rocks are but *partly* crystalline.

Meteorites are described by von Lasaulx in an appendix.

Concerning this treatment he remarks that it is the first time that cosmic rocks have been given a place in a text-book of petrography, but that it seems useful, for purposes of comparison, to have them described in the same work with the terrestrial rocks.

H. Rosenbusch, 1877.—Another important summary of the results of the microscopical investigation of rocks appeared in 1877, under the title *Mikroskopische Physiographie der massigen Gesteine*, by H. Rosenbusch. There was in this work but slight discussion of principles of classification, and the only new factor of note in the system used is the idea expressed in the title, which requires some explanation. All rocks were divided into two classes:

I. Massive rocks ("Massige Gesteine").
II. Stratified rocks ("Geschichtete Gesteine").

A class of Metamorphic rocks was not considered feasible.

"Massive" and "stratified," as used by Rosenbusch in this connection, do not refer to rock textures, as one might suppose from the historic use of the terms; for this primary division was avowedly intended to express an idea, first brought out by Lossen (which will be referred to more fully in a later section of this review), that the most important relation of rocks is the formal one to the earth sphere. Rocks may be considered as having been formed, either at the surface under the influence of gravity, in more or less concentric shells or strata, or, in eruptive bodies of irregular shape and position not determined by gravity. Under this conception all rocks are either stratified or massive. Massive rocks in this sense are also eruptive rocks, but Rosenbusch chose to use the former term in systematic petrography because free from the genetic conception involved in the latter. In view of the evolution of this master's ideas, presented in later works, his language will be quoted:[1] "The former name is to be preferred because it refers only to an undeniable form of

[1] "Der erste Name ist vorzuziehen, weil er sich lediglich auf eine unläugbare Erscheinungsform bezieht und keinerlei irgendwie geartetes Präjudiz über die genetischen Verhältnisse involvirt."

occurrence, and involves no possible prejudice concerning genetic relations."

The controlling criteria in the further construction of Rosenbusch's scheme will be apparent from the following partial tabular statement :

Massive rocks.

A. Orthoclase rocks.

a. Older.

I. Quartzose.

1. Granular = Granite Family.
2. Porphyritic = Quartz porphyry Family.
3. Vitreous = Felsite-Pitchstone Family.

II. Quartz free (3 families similar to those above).

b. Younger.

I. Quartzose.

1, 2. Granular or porphyritic = Liparite Family.
3. Vitreous = Family of the acid glasses.

II. Quartz free (with families as above).

The other large groups are the following :

B. Orthoclase-Nephelite, or Orthoclase-Leucite rocks.
C. Plagioclase rocks.
D. Plagioclase-Nephelite, or Plagioclase-Leucite rocks.
E. Nephelite rocks.
F. Leucite rocks.
G. Non-Feldspathic rocks. Of the Non-feldspathic rocks Rosenbusch remarked[1] that they were all rich in olivine, and might therefore be called *Olivine rocks*.

Each of these groups has Older and Younger divisions, and, within these, families, established in a manner similar to that given for the orthoclase rocks.

In this arrangement *mineral composition* is used, as in Zirkel's system. The *age distinction* is applied without discussion. *Texture* is given a prominent rôle, and *chemical composition is not used*.

Fouqué and Michel-Lévy, 1879.—The first effects of the microscopical study of rocks upon petrographic system in France may be seen in the *Minéralogie micrographique*, by F. Fouqué

[1] "Sie sind sämmtlich reich an Olivin, daher kann man sie kurz als Olivingesteine bezeichnen."

and A. Michel-Lévy, which was published in 1879. While presented as an "Introduction à l'étude des roches éruptives françaises," there is in this work some discussion of principles of classification, and a tabular view of the scheme in use by the authors. Although the system in question has not had much influence except in France, it is of interest from certain new and peculiar conceptions which are given classificatory value in it.

It is first to be noted that Fouqué and Michel-Lévy abandon almost entirely the system of Cordier. Although affirming that rocks are simply the most abundant natural associations of minerals ("les roches ne sont autre chose que les associations minérales naturelles le plus fréquentes"), they proceed to their arrangement under the stated principle that a rational classification of rocks in general must be based upon the following three fundamental characters, namely: (1) The mode of formation; (2) the geological age; (3) the specific mineral properties. The last named character comprises: (*a*) the nature of the integrant minerals; (*b*) the structure of the rock.[1] By the application of the first factor they separate eruptive rocks from those deposited as sediments or as vein filling. By the factor of geological age (the applicability of which is not discussed) they distinguish clearly — "nettement" — between pre-Tertiary and Tertiary or post-Tertiary rocks. It is believed that the same types occur in both groups, following approximately the same order of eruption, with predominance of basic rocks and a tendency to the vitreous condition in the most recent occurrences. In these respects the new French system is practically like others which have been reviewed, but in the use of *structure* and *mineral composition* for the main framework of their system, Messrs. Fouqué and Michel-Lévy apply certain peculiar conceptions requiring some analysis.

Considering that in practically all eruptive rocks there have been two (or more) distinct periods of formation of the primary

[1] "Un classement rationel des roches, en général, doit s'àppuyer sur les trois caractères fondamentaux suivants: 1° le mode de formation; 2° l'âge géologique; 3° la spécification minéralogique. Ce dernier caractère comprend: (*a*) la nature des minéraux intégrants; (*b*) leur structure d'association (structure de la roche.)"

mineral grains, these authors proceed to give a strangely artificial weight to the products of the second period, both in definitions of structure and in classifying rocks by mineral composition. The structures of eruptive rock applied in classification are brought under two groups: "structures granitoïdes" and "structures trachytoïdes." The essential difference between the two is conceived to be that in the granitoid the grains of the two periods of consolidation resemble each other, because of similar conditions of consolidation in the two periods, while in the trachytoid structure there is a marked difference between the two products as a result of changed conditions in the later period. In the rocks commonly called granular it is thought that two generations of mineral grains of approximately the same formal character may usually be recognized. Where no distinction can be made it is rather paradoxically assumed that the grains all belong to the *second* period. But it is to be noted that without this assumption the scheme of Fouqué and Michel-Lévy, as it stands, could not classify such a rock. Porphyries in which the groundmass is granular are, from that fact, classed with perfectly granular rocks.

Under the granitoid group of structures three varieties are recognized: (1) Granitoid proper, in which each individual grain has approximately equal dimensions in all directions, variation in size being disregarded; (2) pegmatoid, the regular or graphic intergrowth of two minerals of simultaneous crystallization; (3) ophitic, characterized by elongated feldspar crystals, and forming a transition to the microlitic structure.

The trachytoid group of structures has likewise three varieties: (1) *Type pétrosiliceux*, characterized by bands of minute spherulites and the presence of the mysterious substance petrosilex or microfelsite; (2) *type microlithique*, characterized by microlites of feldspar, and of other minerals; (3) *type vitreux*, characterized by predominance of amorphous substance.

In explaining the microlitic type the authors point out that their synthetic experiments prove that such microlites are products of *pure igneous fusion*, indicating to them a fundamental

difference between the trachytoid and the granitoid structures, since they believe that certain mineralizing agents ("agens minéralisateurs") are necessary to the latter development.

This view of rock structures makes the shape of the mineral grains all important and casts aside the formal relationship prominent in the porphyritic structure as of little value. The equidimensional *grain* and the elongated *microlite* are placed in fundamental opposition to each other.

The mineralogical composition of rocks is applied for their classification in a qualitative way, similar in some respects to that adopted by the German petrographers, but with the all important modification that *only the minerals of the second period of consolidation are considered.* Such a principle may be designated as subjective, extremely unnatural and highly artificial. There is in this system no attempt to express the chemical composition of the rock in terms of its minerals, for in some cases all the minerals of a rock are used in its classification, where there was no *first* period of consolidation, and in other cases only a small portion of the constituents, as in porphyries with abundant phenocrysts and microlitic groundmasses. Since in porphyries this portion of second consolidation bears no definite quantitative relation to the mass as a whole it must often happen by this system that rocks of widely different chemical composition will be brought together and, conversely, that rocks of the same chemical character and even of the same magma will at times be separated. For example, certain intrusive quartzose hornblendic diorite-porphyries of the Rocky Mountain region, in which hornblende and plagioclase are developed entirely in phenocrysts, would fall among the microgranulites while their granular equivalents would be quartz-diorites. It is also clear that all but granular rocks would be classified in this scheme by their most obsure constituents, often to the neglect of every prominent megascopic character, and systematic petrography would become purely a microscopical science. It is interesting to recall at this point the principle announced by these authors and quoted above that a rational classification of rocks must be

based upon the "fundamental characters" whose application has been reviewed,

In practice, Fouqué and Michel-Lévy give the first importance to the colorless constituents, quartz, feldspars, feldspathoids, etc., to produce series within which the ferromagnesian minerals are used to make subdivisions. The existence of certain phenocrysts is recognized, in the naming of rocks, in a few cases only.

The petrographic system for eruptive rocks elaborated by Fouqué and Michel-Lévy in 1879 has remained the system of France to the present time, with but slight change.

In 1889 Michel-Lévy compared the results of their system with those of the Rosenbusch system, soon to be discussed, in a work entitled *Structures et classification des roches éruptives.*[1] This discussion presented no new propositions of note excepting a plan of expressing the structure and mineral composition of any given rock by a formula. The principles which must govern the classification of eruptive rocks are concisely stated as follows:

[1] Paris, 1889, pp. 93.

> It is neccessary to base the classification and nomenclature of rocks upon positive facts, independent of all hypothesis. Modern petrography possesses the means to accomplish this end, since the principal structures or modes of association of the minerals are well known and the minerals themselves may be determined with precision. It is, then, exclusively structure and mineral composition which must be relied upon in the classification and nomenclature of rocks.[1]

It is to be remarked, once more, that chemical composition is not taken into account by Michel-Lévy, either directly or indirectly, since the partial mineral composition used by him in classification is clearly not an expression of the chemical composition of the magma nor of any definite part of it. The substance classified is not the rock but merely that variable portion

[1] "Notre conclusion, ... est qu'il faut baser la classification et la nomenclature des roches sur des faits indépendants de toute hypothèse, et de nature positive. La pétrographie moderne dispose de moyens suffisants pour atteindre ce but sans hésitation: on est d'accord sur les principales structures d'association des minéraux des roches; on sait déterminer ces minéraux avec précision. C'est donc *exclusivement* sur la structure d'association et sur la composition minéralogique que nous persisterons à nous appuyer pour classer et nommer une roche." *Loc. cit.*, p. 87.

of the rock which the investigator judges was in a fluid or pasty condition at the beginning of the second period of consolidation —the "pâte."

Samuel Allport.—During this period in which Zirkel, Rosenbusch, Fouqué and Michel-Lévy were formulating more or less distinct advances in systematic petrography, the English students of rocks made but slight positive contributions in this direction. The condition of the science may be best appreciated by reference to the various short discussions of principles of classification by Samuel Allport. This careful investigator often pointed out the fallacy of the age distinction, so clearly illustrated by the long-known ancient lavas of the British Isles, and also the importance of Judd's discovery of the intimate relationship of coarsely crystalline and volcanic rocks. This was cited to disprove the idea that a sharp line could be drawn between the Plutonic and Volcanic rocks. But Allport considered it premature to suggest any great changes either in classification or nomenclature.

Clarence King, 1878.—In America no original contributions to systematic petrography were made prior to the microscopical period. The earliest use of the knowledge gained in that period was probably by Clarence King,[1] whose appreciation of its value led to the report upon the Microscopical Petrography of the 40th Parallel rocks by Zirkel, and who, also, applied certain supposed facts resulting from microscopical research in his own discussion of the classification of volcanic rocks. The proposition referred to has had little influence upon petrographic system, but has a certain importance from the standpoint of this review as illustrating again the dangers of applying genetic ideas in the classification of igneous rocks.

King accepted the law of Bunsen and the law of succession of volcanic rocks advocated by von Richthofen, which have been stated. He also considered that "a sharp line is to be drawn between the so-called Plutonic rocks and the true igneous ones." The microscopical studies of which he had knowledge led him

[1] Report of the Geological Exploration of the Fortieth Parallel, I. *Systematic Geology*, pp. 705–25, Washington, 1878.

to the strongly stated conclusion that "all the volcanic rocks show abundant evidence of fusion in the presence of glass base and glass inclusions, while the group which is typified by granite never shows the slightest trace of the effects of fusion." All known characters of plutonic rocks are interpreted as proving them to be extreme products of the metamorphism of sediments. After discussion of the cause of generic differences of volcanic rocks, in which certain new hypotheses concerning magmatic differentiation are developed, King proposes the following systematic arrangement for the family of volcanic rocks, including therein all believed to be of truly igneous origin:

Genera.— (1) Propylite; (2) Andesite; (3) Trachyte; (4) Neolite. Expressions of time, according to von Richthofen's law of succession, and of depth owing to secular refrigeration.

Species.— Expressions of chemical differentiation by specific gravity of mineral ingredients, grouping under the law of Bunsen.

Three species only were recognized under each genus, representing respectively the quartz, biotite or hornblende, and pyroxene-bearing forms.

Varieties.— Expressions of range of texture according to predominance of secreted crystals, groundmass, or base.

M. E. Wadsworth, 1884.— Under the title *Lithological Studies; A Description and Classification of the Rocks of the Cordilleras*, M. E. Wadsworth published, in 1884, the first part of a projected comprehensive work, intended to present a new classification of rocks. This first part was devoted to a discussion of principles and the beginning of the descriptive portion. Wadsworth denounced all existing systems as highly artificial, and stated, as the basis of his own more natural system, the belief that "the older rocks now classed as distinct species are rocks that were once identical with their younger prototypes." "The order [of his system] will be to pass from the glassy to the most perfectly crystalline state; from the least altered to the most altered; from the most basic toward the most acidic; from the non-fragmental to the fragmental or clastic." He plunged at once into a description of ultrabasic rocks, without explaining the

proposed application of his asserted principle to the construction of a system, and no further portions of the projected work have appeared. It is plain that the basis of Wadsworth's conception is contrary to known facts of petrogenesis. A direct contribution to petrographic system is afforded by the proposition made by Wadsworth to group terrestrial and meteoric masses together, applying to them a single system and nomenclature. The descriptive portion of the published work is, in fact, mainly occupied with discussion of meteorites rich in iron. Wadsworth thus goes a step further than von Lasaulx, who treated meteorites in an appendix to his discussion of terrestrial rocks (p. 455).

It is hoped that the trend of the evolution of systematic petrography during the earlier portion of the microscopical era has been fairly indicated in the preceding pages. The tendency, most natural under the circumstances, was to overestimate the systematic importance of some of the discoveries made through the microscope, and to slight other, more fundamental, properties or relations of rocks. Many new rock names were proposed and usage became fixed and extended in directions where it had never been well grounded. Protests against the tendency of the times were numerous, and especially from the geologist's standpoint. Many of these protests were of little influence, because based upon imperfect appreciation of the situation; others were far too conservative in spirit.

J. D. Dana, 1878.—As an example of the conservative geologist's view at this time may be cited the discussion of petrographic system by J. D. Dana in an article published in the *American Journal of Science* in 1878 under the title "On some Points in Lithology."[1] This article refers to the *Mikroskopische Physiographie* of Rosenbusch, and to other recent works, and may be taken as expressing the author's view of petrography at the stage of its development just reviewed.

Lithology, according to Dana, is charged with the descrip-

[1] *Amer. Jour. Sci.*, 3d ser., Vol. XVI, p. 335, 1878.

tion and naming of rocks. It has "to note down their distinctions in such a manner as shall best contribute to the objects of geology." "From granite down they [rocks] are with very few exceptions mixtures of minerals, as much so as the mud of a mud bank." "Strongly drawn lines exist nowhere." "Rocks are therefore of different *kinds*, not of *different species;* and only those mixtures are to be regarded as *distinct kinds* of rocks which have a sufficiently wide distribution to make a distinct name important to the geologist."

Dana discusses the bases of classification adopted by petrographers of this time, such as age, structure, and contents in certain minerals, and objects to most of them as trivial or wrongly used. He then proposes an arrangement of the "Crystalline rocks, exclusive of the calcareous and quartzose kinds," under the following groups :

I. Mica and potash feldspar series — Granite, gneiss, mica schist, trachyte, etc.

II. Mica and soda-lime feldspar series — Kersantite, kinzigite, ditroite, phonolite, etc.

III. Hornblende and potash feldspar series — Syenite, hornblende-schist, foyaite, etc.

IV. Hornblende and soda-lime feldspar series — Diorite, andesite, euphotide, etc.

V. Pyroxene and potash feldspar series — Amphigenite.

VI. Pyroxene and soda-lime feldspar series — Augite-andesite, norite, dolerite, etc.

VII. Pyroxene, garnet, epidote, or chrysolite rocks, containing little or no feldspar, lherzolite, dunite, garnetite, etc.

VIII. Hydromagnesian and aluminous rocks. Chloritic, talcose, and other schists, serpentine, etc.

While Dana does not refer in this article to the broader grouping of rocks, it appears, from various editions of his *Manual of Geology*, that he uses mode of origin to distinguish the three great classes — Igneous, Sedimentary, and Metamorphic — in discussing that question; but, in arranging rocks for description, he abandons that principle, and makes another division as more convenient. Convenience of presentation, and not expression of natural relations, is really the object of Dana's arrangement. It

is, therefore, not strictly a petrographic system. In the second edition of the *Manual* (1874), igneous and metamorphic groups were separated in description; but, probably for the reason that such a course involved the splitting up of granitic, syenitic, and other types supposed to be metamorphic in part and eruptive in part, Dana had, in 1878, evidently adopted the arrangement found even in the last edition of the *Manual* (1895), whereby *crystalline* and *fragmental* were opposed to each other, as by Zirkel in 1866.

Dana was never able to adopt the modern petrographic systems, founded so largely upon erroneous assumptions, like the age distinction among igneous rocks, or upon genetic views with which he was not in accord, and contented himself with an arrangement of convenience. The main features of this order of description appearing in the *Manual of Geology*, 1895, are seen from the four primary groups under which all rocks were treated:

1. Limestones, not crystalline.
2. Crystalline limestones.
3. Fragmental rocks, not calcareous.
4. Crystalline rocks.

The crystalline rocks were described under five heads:

I. Siliceous rocks, or those consisting mainly of silica.
II. Rocks having alkali-bearing minerals as chief constituents.
III. Saussurite rocks.
IV. Rocks without feldspar.
V. Hydrous magnesian and aluminous rocks.

The second group was divided nearly as in the proposition of 1878, above cited. This resulted in bringing together such unlike things as granite, greisen, minette, slate, agalmatolite, porcelain jasper, obsidian, etc., in the "Potash Feldspar and Mica Series."

Karl A. Lossen.—Among other protests raised by geologists against the tendency to treat rocks fom the microscopist's alleged narrow standpoint, one of the more philosophical discussions had an acknowledged effect making it worthy of notice; namely, that by Karl A. Lossen, himself a petrographer of dis-

tinction, yet in first degree a geologist, prominent upon the Prussian geological survey.

The views held by Lossen were repeatedly expressed, and were summed up in a discussion of principles entitled *Über die Anforderungen der Geologie an die petrographische Systematik*.[1] The "demands" here forcibly expressed are based upon the idea that, *because the rock is a geological body, the geological relations of rocks must be recognized as petrographical relations.* Of all the geological relations of rocks Lossen selected that which seemed to him the most important, and claimed that that principle should be used as the primary factor in petrographic classification. The relation of rock masses to the earth sphere appealed to Lossen as all important, and on that criterion all rocks were considered as *stratified* or *massive*. Stratified rocks were defined as those accumulated upon the earth's surface under the controlling influence of gravity, causing them to assume in some degree the form of concentric strata normal to the radius of the earth. The material of massive or eruptive rocks, on the other hand, was viewed as having been forced from the depths directly against the influence of gravity, consolidating like a casting, under the control of surrounding conditions. Surface lavas, spreading out in sheets, while controlled largely by gravity in their formal relations, were referred by Lossen to massive rocks, because possessing the resemblance to a casting from one pouring, and not as built up by successive additions, layer upon layer. It will be seen that the molten condition of magmas was actually a leading factor in Lossen's idea, although the avowed intention in using *eruptive* as an alternative for *massive* was to express the force opposed to gravity, and not the molten state which rendered them susceptible to that force.

Lavas are not the only rock masses difficult of consistent treatment under Lossen's principle. Pyroclastic tuffs were considered as illustrating the fact that "das Ineinandergehen zum Wesen der Gesteinsnatur gehört." Lossen confessed, further, that rocks of the first crust of the earth, according to the nebu-

[1] *Jahrbuch der k. pr. geol.* Landesanstalt, 1883, p. 486.

lar hypothesis, would necessarily be separated from his eruptive class, but he considered this point immaterial because he doubted whether any such rocks were known. Metamorphic rocks are of such diverse origin and present such difficulties to the systematist that Lossen considered it inadvisable to treat them as a distinct class.

In this discussion by Lossen, as in the majority of those emanating from geologists, no appropriate distinction is made between the rock mass as a formal unit and the material within it, the rock proper. The primary division of Lossen is one of rock masses, not of rocks. The consideration of the form and position of these masses with regard to the controlling influence of gravity or the opposing eruptive force, leads to only one of many ways in which the geologist must classify rock bodies. Other elemental subdivisions of the same bodies are necessary. The geologist is, indeed, obliged to make and discuss all such fundamental distinctions. The petrographer, on the other hand, should not only be at liberty to select, but, in order to secure logical excellence for his system, *must* choose, as his primary principle, that one most closely connected with the factors which he has adopted for use in the further construction of the systematic arrangement of rocks. It is clear that all igneous rocks, those produced by the consolidation of molten magmas, possess, from this origin, material properties most useful in their detailed classification. If arrangement by a certain characteristic due to this origin is desired, it matters not where the rocks occur in the earth. They may belong to the primeval crust, or form injected masses of whatever size, shape, or attitude, or appear on the surface in lava streams. If it was mode of origin, not formal relations to the earth, which gave igneous rocks the common characters used in their systematic arrangement, then mode of origin is logically the principle to be used by the petrographer to bring them into one grand division.

H. Rosenbusch, 1887.—As has been mentioned, the force of Lossen's claim, as made in earlier publications, was admitted by H. Rosenbusch, in the first edition of his *Mikroskopische Physio-*

graphie der massigen Gesteine, "massig" being used in the sense explained by Lossen, and not in that of textural condition. In the second edition of this widely-used handbook, which appeared in 1887, Rosenbusch repeated his approval of Lossen's proposition, and in the revision of his petrographic system further emphasized geological occurrence as a factor of prime classificatory value for eruptive rocks. The great changes in system found in this volume make it practically a new work, but a detailed statement of its scheme seems unnecessary since all petrographers may be assumed to be familiar with it.

In the decade since the appearance of the first edition, Rosenbusch effected a complete change of systematic base in some important respects, the reasons for which are given in the preface. He now considers rocks as the documents in which the history of the earth is written, and petrography, as the science which teaches us how to decipher those documents, becomes to him *a historical and not a descriptive science*. To quote his declaration:

> The recognition of these relations made the new edition of this book practically a new work. Its end will have been achieved if I have succeeded in procuring for this fundamental conception a general acceptance, and have demonstrated that rock structure affords the safest and most productive means for the construction of a natural system of rocks.[1]

A natural system of rocks must therefore be historical, *i. e.*, genetic. Plainly the logical analysis of the broad science of rocks presented by Naumann was either forgotten or ignored by Rosenbusch.

With this statement of controlling principles in mind, one involuntarily recalls that in the first edition of the *Mikroskopische Physiographie* the rocks to be discussed were designated *massive* in preference to *eruptive* because the former term was considered free from expression of any genetic idea. In this second edition, while advocating the genetic basis of classifica-

[1] "Die Erkenntniss dieses Verhältnisses machte die neue Auflage dieses Buches zu einer Neubearbeitung. Der Zweck derselben wird erreicht sein, wenn es mir gelungen ist, dieser Grundanschauung eine allgemeinere Anerkennung zu verschaffen und darzuthun, dass die Gesteinsstructur das sicherste und ausgiebigste Mittel zum Aufbau eines natürlichen Systems der Gesteine an die Hand giebt."

tion as all important, Rosenbusch retains the group term *massive*, yet in both works it is clearly the igneous origin which is first in mind and which is recognized as of prime importance in producing rock structure, chosen as the leading factor in constructing the new system.

After having stated his belief that rock structure is the best basis of classification of "massive rocks" Rosenbusch proposed to divide them into three groups: (1) Deep-seated rocks ("Tiefengesteine"), (2) Dike rocks ("Ganggesteine"), and (3) Effusive rocks ("Ergussgesteine"). The critic is obliged to point out that this proposition is inconsequent, for not only is structure not expressed in the terms chosen, but another distinct factor is expressed, namely, mode of occurrence. The further development of Rosenbusch's scheme makes it clear that he did not intend to emphasize the actual facts of geological occurrence, plainly as he stated them, but rather to express in this way his conception of the genesis of structure. Recognizing that different structures result from the consolidation of a given magma according to the attendant conditions, Rosenbusch selected the geological factor appearing to him of greatest influence among many conditions and made that the expressed basis of structural classification. Since simplicity and logical directness are surely of utmost importance in systematic constructions the unnecessary indirectness of this proposition may be designated a fatal weakness. Furthermore, the geologist is warranted in objecting to it because the expressed division of igneous rocks is one which he has used in the past and must use in the future, in its literal and appropriate sense, quite apart from the idea hidden in the terms of Rosenbusch's system.

To the above noted criticisms of Rosenbusch's first application of structure in classification must be added another, based upon the fact that the division of *Dike rocks* was not in reality provided for rocks occurring in dikes, but for a group of rocks for which Rosenbusch assumed a certain genesis. An hypothesis of magmatic differentiation and assumptions of limited occurrence and of characteristic structure are all involved in the dis-

crimination of the group named "Dike rocks." In this light this group is certainly not co-ordinate with the other two of the same rank as defined.

In the subdivision of the three classes of "Massive rocks" Rosenbusch applied mineral composition as a factor, producing Families. The quantitative composition, either chemical or mineral, received no expression, so that, for example, anorthosite and the most highly pyroxenic gabbro or norite are found together in the gabbro family. Moreover in the porphyritic Dike rocks only the phenocrysts are considered in determining the systematic position of a given rock. Thus a porphyry having the chemical composition of a granite is referred to syenite-porphyry in case its excess of silica chances to be confined to the groundmass, while had quartz phenocrysts been present it would have been called granite-porphyry. In the Effusive rocks, Rosenbusch hesitates to apply the same rule consistently. The families of these rocks are defined in very general terms as the "equivalents" of certain granular rocks and described as containing certain phenocrysts in a groundmass of variable appearance.

As in the earlier system, all feldspar-free rocks of the deep-seated class are united as Peridotites. The peculiar character of the Dike rocks as a division not co-ordinate or co-extensive in range with the Deep-seated or Effusive rocks appears in the fact that mineralogical groups corresponding to the granites, syenites, and diorites, only, are recognized.

Geological age is acknowledged by Rosenbusch to have been assigned a higher value in classification than belongs to it, but it is retained, in the Effusive class, and the use of duplicate terms perpetuated.

H. Rosenbusch, 1896.—The third edition of the "*Mikroskopische Physiographie der massigen Gesteine*," issued in 1896, contains no essentially new systematic features. The principles above set forth are reaffirmed, and, save for the elaborated discussions of magmatic differentiation, which show more plainly than in the preceding edition the strong influence of hypo-

thetical considerations in giving form to this system, there is little of note to comment upon in this place. In discussing the essential characters of the three groups of Dike rocks, Rosenbusch brings out more forcibly than before the genetic idea really lying at the base of the distinction of the Dike rock class. In connection with the discussion of the Dike rocks it is suggested that a further class may be necessary to include the intrusive rocks of sheets and laccoliths which seem to him to possess distinctive structures.

That the system of Rosenbusch does not result in a consistent and logical classification of igneous rocks is abundantly illustrated by numerous instances, many of them freely acknowledged by the author. The family of the diabase rocks furnishes one of the most notable cases. In 1887 these rocks were classified with the deep-seated rocks, although many of them were known to be effusive; in 1896 the same rocks are placed with the effusives, with the statement that many are intrusive. Placed in the effusive class, they are acknowledged to be partly of older and partly of younger age, but no age distinction is thought to be practicable.

Justus Roth, 1883.—Shortly before Rosenbusch issued the second edition of his *Physiographie*, there appeared a complete systematic discussion of rocks by Justus Roth, in the second volume of his *General and Chemical Geology*.[1] Petrography is defined by Roth as the science of the mode of origin, constitution, and alteration of rocks; *i. e.*, the petrology of many English and American writers. In introducing the systematic descriptive part of the subject, Roth remarks: "The difficulty in constructing a system of rocks is completely expressed in the term *aggregate*, and thereby all recourse to genera and species is prohibited."[2] From the nature of rocks and the conditions of

[1] *Allgemeine und chemische Geologie;* Zweiter Band, "Petrographie" (Berlin, 1883–1885), pp. X + 695.

[2] "Die Schwierigkeit der Systematik der Gesteine ist durch die Bezeichnung Aggregat vollständig ausgedrückt und damit alle Anlehnung an Gattungen und Species ausgeschlossen," *loc. cit.*, p. 41.

their origin, he thinks that every system must so largely represent individual opinion that probably no one system can ever receive universal recognition.

The systematic arrangement of Roth is, in its general outline, as follows:

A. Rocks composed essentially of minerals.
  I. Plutonic (consolidation products of molten magmas). Free from fossils, composed of minerals or substance chemically like a mineral aggregate.
    1. Eruptive. (Breaking through other rocks.)
      a. Pre-Tertiary.
      b. Post-Cretaceous.
        Appendices to *a* and *b* contain rocks produced by weathering. Tuffs.
    2. Crystalline schists.
      Appendix-Weathering products.
  II. Neptunic.
    1. Partly fossiliferous; composed of minerals and of the products of the decay, decomposition, and attrition of minerals.
      a. Precipitates from solution.
      b. Deposits from suspension.
    2. Clastic, composed of rock fragments.
B. Rocks composed essentially of organic remains.
C. Products of contact metamorphism.

It will be observed that the ancient crystalline schists are regarded as the primary crust of consolidation of the earth.

The geological factors of origin, relations, or age, are variously applied in the construction of this scheme, and in constitution the distinction between mineral and rock particles is made. All Plutonic rocks are regarded as consisting essentially of silica or *silicates*, excepting that in the crystalline schists *carbonates* appear. The silica free minerals—apatite, magnetite, ilmenite, etc., are treated as accessory constituents. This exclusion of the latter group of minerals from a position of systematic importance is not discussed by Roth, but its evident result is that in certain rocks, *e. g.*, those rich in magnetite, the components do not have their natural and logical weight in classification.

Of the pre-Tertiary eruptive rocks, Roth makes, for convenience, three divisions:

I. Orthoclase rocks.
II. Plagioclase rocks.
III. Peridotites.

The first two of these groups should, logically, have been united systematically in the division of Feldspathic rocks, including all with appreciable content in feldspar, since the Peridotites are defined as free, or nearly free, from feldspar. The question of recognizing the quantitative relations of mineral constituents is not mentioned by Roth.

The silicate minerals are applied by Roth for the subdivision of the three main groups in the usual way, and by means of *structure* the granular, porphyritic, and glassy varieties are distinguished.

In the detailed treatment of Eruptive rocks, as in the arrangement of Crystalline schists, the Neptunic rocks and the Classes B and C, mentioned above, Roth's order of presentation and discussion can hardly be said to be systematic. It is an arrangement for convenience of description, not based upon the logical application of principles; and it is, therefore, not desirable to devote more space to its analysis in this review.

E. Kalkowsky, 1886.— A condensed text-book on rocks was published by E. Kalkowsky, in 1886, with the title *Elemente der Lithologie*.[1] For the primary division of rocks the author formulates an original criterion, and proposes two great classes:

I. "Anogene"—of which the material came to the place of rock formation from *below*.
II. "Katogene"—of which the material was derived from *above*.

These correspond closely to the eruptive and sedimentary divisions of other authors.

For the classification of the "Anogene" rocks Kalkowsky applies the following factors: (1) Chemical composition as represented in mineral composition; (2) the usual age distinction; (3) structure. He rejects genetic distinctions as unsuit-

[1] Heidelberg, 1886, pp. 316.

able. In detail Kalkowsky's scheme is similar in its results to that of Zirkel, but, as he does not define his smaller rock divisions, a further discussion of his arrangement seems unnecessary. The definitions are omitted, according to the author, because the student must learn to know the rocks by the study of named hand specimens and will, therefore, find out what they are without definitions.

J. J. Harris Teall, 1886, 1888.—The most extensive treatise on rocks thus far published in England is the descriptive work *British Petrography*, by J. J. Harris Teall, issued almost simultaneously with the second edition of Rosenbusch's *Massige Gesteine*. This work lays no claim to being a systematic petrography, and describes almost exclusively the igneous class; but from its scope a discussion of principles of rock classification was necessary, as explanatory of the arrangement actually used. Teall considers rocks so complex and indefinite in character that in the existing state of knowledge no true systematic arrangement is possible. His order of presentation is, in fact, one of convenience, and does not express his own views of the most natural basis of classification.

In discussion of principles, Teall points out that chemical composition, as the constant and primary character of igneous rocks, is the natural basis of classification and in accordance with the Bunsen law of two magmas. He, however, does not work out any new proposition to use chemical composition. The arrangement under which rocks are described is a mixture of the methods of Rosenbusch and Michel-Lévy. All igneous rocks are placed in seven groups, as follows:

A. Rocks composed of the ferro-magnesian minerals: olivine, enstatite, augite, hornblende, and biotite. Feldspar absent; or, if present, occurring only as an accessory constituent.

B. Rocks in which plagioclase is the dominating feldspathic constituent. Nepheline and leucite absent. Orthoclase is frequently present.

C. Rocks in which orthoclase is abundant. Plagioclase usually present. Nepheline and leucite absent.

D. Rocks containing nepheline or leucite; sometimes nepheline and leucite.

E. Rocks not included in any of the preceding groups.
F. Vitreous rocks.
G. Fragmental volcanic rocks.

It will be seen that this grouping is mainly mineralogical and does not express the quantitative element in any logical way. It practically recognizes the entrance of feldspar, in any amount above that of the undefined "accessory" rôle, as creating a large group of *feldspathic rocks*. The subdivision of these groups is first on some further mineral distinction and after that occurrence and texture enter combined into the system by distinguishing rocks of *granitic* from those of *trachytic* texture, using these terms in the sense of Fouqué and Michel-Lévy, and conceiving that the result is practically to separate *plutonic* or deep-seated from *volcanic* or effusive rocks. Age is not introduced as a factor.

Within the last twenty years several attempts have been made to apply, *in extenso*, the chemical composition of rocks for their classification. These attempts have been prompted by various motives. Some appear to have no really practical object, viewed from the petrographer's standpoint; others are connected with hypotheses of magmatic differentiation; and still others have been inspired by a realization of the complexity of the problem of a rational arrangement of rocks on the basis of their numerous and highly variable mineral constituents. It appears to the writer, however, that it may be fairly said of all these attempts that they are either not classifications of *rocks*, or that they are not actually *chemical* classifications.

Franz Schröckenstein, 1886, 1897.—Two peculiar attempts by Franz Schröckenstein, an Austrian writer, to discuss the chemical composition of silicate rocks, irrespective of their origin, and upon that basis to classify them, are mentioned here only for the sake of completeness, as these attempts have no direct bearing upon a logical system of rocks. The writer has seen only the more recent of the essays in question,[1] depending for the

[1] "Silicat-Gesteine und Meteorite," *Petrographisch-chemische Studie auf Grundlage des neuesten Standes der Wissenschaft bearbeitet.* Prag, 1897.

earlier one[1] upon the summary given by F. Loewinson-Lessing.[2]

Schröckenstein's view of igneous rocks will, on account of its fantastic imaginings, impress many a reader as belonging rather to the eighteenth, or a still earlier, century, than to the close of the nineteenth; and, although his propositions are of no consequence to petrography, the fact that they have been put forth at all, in the very last decade of the period in review, has a certain melancholy interest.

Schröckenstein considers the original crust of the earth to have been a *silicate of alumina*, probably with excess of silica. This simple primary magma is conceived to have been first rendered impure by meteoric showers, introducing lime, magnesia, and iron. At a later period the alkalies and water were precipitated from the atmosphere. The alkalies are considered as of very subordinate ("nebensachlich") importance and the chemical problem of rocks, as the author views it, is to compare the relative amounts of the original alumina silicate and the meteoric impurities. That is to say, *the author proposes classes according to the degree of adulteration of the original magma and orders according to the character of the adulterant.*

The method followed by Schröckenstein in comparing analyses of silicate rocks appears to be somewhat as follows:

First, magnetite is calculated out, as an *extraneous substance*, whenever the analysis is sufficiently modern, through determinations of both ferric and ferrous oxides, to give a basis for such calculation. When the analysis is inadequate and the iron is lumped under one or the other oxide, the result is accepted by the author and Fe_2O_3 is supposed to replace alumina or FeO is added to MgO and CaO. Not until magnetite is deducted does Schröckenstein consider that the real rock is under discussion. Inasmuch as he states that after deducting magnetite there is either no iron left or but one oxide appears, it is evident that the

[1] Ausflüge auf das Feld der Geologie," *Geologisch-chemische Studie der Silicatgesteine*, II Auflage, Wien, 1886.

[2] "Studien ueber die Eruptivgesteine," *Compte-Rendu, VII Cong. Géol. Internat.*, 1899, p. 196.

maximum possible amount of magnetite is deducted. The remainder is then calculated to 100. The analyses are not given in their original form.

The systematic plan of Schröckenstein consists, in his later publication, in establishing five classes of silicate rocks, according to the relations of Al_2O_3 to RO ($=CaO + MgO + FeO$) as shown by the *percentages* of the calculated remainder after deducting magnetite.

I. $\frac{RO}{Al_2O_3} < \frac{1}{4}$; II. $\frac{RO}{Al_2O_3} < \frac{1}{2} > \frac{1}{4}$; III. $\frac{RO}{Al_2O_3} < \frac{3}{4} > \frac{1}{2}$;

IV. $\frac{RO}{Al_2O_3} < \frac{1}{1} > \frac{3}{4}$; V. $\frac{RO}{Al_2O_3} > \frac{1}{1}$.

Two orders appear under each class according as lime or magnesia dominates.

Although Schröckenstein professes to use the latest information, as stated in the title of his recent publication, his results are based upon the discussion of 340 analyses, many of them old, while on the other hand no single one of the hundreds of analyses made in the laboratory of the United States Geological Survey, within the past twenty years, is utilized. Hundreds of European analyses of recent date are also ignored.

It seems unnecessary to give any further details concerning Schröckenstein's propositions. He is not actually treating rocks and his superficial considerations of chemical composition can have no bearing upon true petrographic system.

H. O. Lang, 1891.—An attempted arrangement of igneous rocks on a chemical basis by H. O. Lang,[1] in 1891, is founded on the idea that since the feldspars are the most important constituents of eruptive rocks, an appropriate and practical chemical basis of classification may be found in the relations of the bases potash, soda, and lime, the distinctive elements of the various species of feldspar. In one case Lang used the percentage

[1] "Versuch einer Ordnung der Eruptivgesteine nach ihrem chemischen Bestande," *Tscher. Min. Pet. Mitth.*, XII, 1891, p. 199.

"Das Mengenverhältniss von Calcium, Natrium, und Kalium als Vergleichungspunkt und Ordnungsmittel der Eruptivgesteine," *Bull. Soc. Belge de Géol.*, 1891, V, p. 123.

amounts of the oxides found by analysis, and in the other the amounts of the elements potassium, sodium, and calcium. Here again is the situation that only a part of some rocks is actually under discussion, and the result can be of no real value to petrography.

F. Loewinson-Lessing, 1890, 1897. In 1890 an attempt at a chemical classification of igneous rocks was made by F. Loewinson-Lessing,[1] based upon the quantitative relations of silica to the various oxides of the bases, grouped under R_2O, RO, and R_2O_3, as shown in *percentages* by bulk analysis. By means of empyrical formulæ the author thought to find a way of expressing regular relationships supposed to exist between the silica contents and the various oxide groups. Rocks exhibiting the following simple relationships were designated *types*, I to V being the principal ones, and VI to IX intermediate:

Acid Rocks

$$\text{I. } SiO_2 = 2(R_2O + RO) + R_2O_3 + Q \text{ .}$$

$$\text{VI. } SiO_2 = \tfrac{3}{2}(R_2O + RO) + R_2O_3 + Q \text{ .}$$

Neutral Rocks

$$\text{II. } SiO_2 = 2(R_2O + RO) + R_2O_3 \left(\text{II} = \frac{\text{I} + \text{IV}}{2}\right) \text{ .}$$

$$\text{VII. } SiO_2 = \tfrac{3}{2}(R_2O + RO) + R_2O_3 \text{ .}$$

Basic Rocks

$$\text{III. } SiO_2 = R_2O + RO + R_2O_3 \left(\text{III} = \frac{\text{II} + \text{IV}}{2}\right) \text{ .}$$

$$\text{VIII. } SiO_2 = R_2O + RO + \tfrac{1}{2}R_2O_3 \left(\text{VIII} = \frac{\text{III} + \text{IV}}{2}\right) \text{ .}$$

Ultra Basic Rocks

$$\text{IV. } SiO_2 = \text{or} < RO \text{ .}$$

$$\text{IX. } SiO_2 = \tfrac{1}{2}RO \text{ .}$$

$$\text{V. } SiO_2 = O \text{ .}$$

Since percentages instead of molecular ratios were used, the simple relations here adopted have no real significance as expressing a regular connection between chemical and mineral composition. This fault was perceived by the author and cor-

[1] "Étude sur la composition chimique des roches éruptives," *Bull. Soc. Belge de Géol.*, 1890, IV, Mem., p. 221.

rected in the publication to be discussed below. These so-called types were assumed by Loewinson-Lessing to correspond more or less closely to certain commonly known rock groups.

The more elaborate discussion of the chemical relationships of igneous rocks by Loewinson-Lessing, presented to the International Geological Congress at St. Petersburg, in 1897, and published two years later in the *Compte-Rendu*, deserves somewhat fuller consideration.[1] A brief statement of the author's point of view is desirable before explaining the system proposed.

In reviewing the applicability of various factors in producing a rational system, Loewinson-Lessing asserts that the mineral composition of a rock is a function of its chemical composition. The exceptions to this rule admitted by him are of little importance. Then follows the further statement that the principle or characteristic of mineral composition as a basis of classification is faulty and unsatisfactory because it does not show the relative abundance of the minerals in the various rocks. That is, however, as it appears to the writer, not the fault of the *principle*, but of the manner in which it has been applied in existing systems. If mineral composition is a function of the chemical composition, it is just as capable of expressing the constitutional relations of rocks as the latter, if properly used. The real objection to its application in the quantitative way, necessary to this expression, is simply one of practicability. The problem is too complex.

As for his own system, Loewinson-Lessing starts from the idea that eruptive rocks may be considered as *silicate rocks* and classified as such. Whatever the facts as to predominance of silicates in these rocks may be, it seems to the writer that this conception is not complete as to its basis of fact, and is thus inadequate to serve as a means of classification. Further fundamental propositions enunciated by the author are that: (1) silicate rocks should be classified by the same artificial means as the silicates themselves; (2) while rocks are not stoichiometric

[1] F. LOEWINSON-LESSING, "Studien über die Eruptivgesteine," *Compte-Rendu de la VII session du Congrès Géologique International, Russie*, 1897, pp. 193–467.

compounds, they are not accidental mixtures; (3) one must consider the relative amounts of *all* oxides of bases to each other and to silica; (4) as silica is the dominant constituent it is proper to take it as the basis for the primary classification; (5) the next factor to be applied must be the contents in the three oxide groups, alkalies, alkaline earths, and the sesquioxides; (6) various single oxides may be used for further subdivisions. From this statement it might be supposed that a classification created by the successive use of the chemical factors named was to be set up by Loewinson-Lessing, and such an arrangement of magmas would have claim to being a chemical classification. But the author does not do that, as we shall see.

The actual system proposed by Loewinson-Lessing is to use the silica contents for the formation of four general groups: (1) Acid rocks; (2) Neutral rocks; (3) Basic rocks; (4) Ultrabasic rocks.

The second division is obtained by taking a certain number of analyses representing known rock families (established on the unsatisfactory basis of mineral composition) and determining the *mean* of these analyses, which is then set up as the composition of a rock *type*, and its formula and coefficient of acidity are ascertained.

It is clear that the grist of this mill depends entirely upon what is put into the hopper. It is not a chemical classification but a chemical *characterization* of mineralogical rock groups arbitrarily selected by the author. It will, of course, be possible to secure means corresponding to any formula desired as a type, and the rocks thus having typical position could be adopted as centerpoints of groups or families. For the ordinary range of rocks these types would often coincide with recognized rocks, assigned certain names in existing systems, and these names might then be given by redefinition to the families thus indicated. But what would be the purpose of such a scheme? It could not express the existing relations between the mineral composition of the rock and the chemical constitution of the magma.

A. Osann, 1900, 1901.—A further attempt to utilize chemical composition as a factor in the classification of igneous rocks was made by A. Osann in the closing year of the century. Under the title "Versuch einer chemischen classification der Eruptivgesteine"[1] Osann essays to use chemical composition as a supplement to mineral and textural characters, by establishing various chemical types within rock families formed upon the Rosenbusch system. The author accepts the classes of deep-seated, dike and effusive rocks, in the Rosenbusch sense, and the vaguely defined families established upon mineral composition. Realizing that by this latter factor, as currently applied, the relative abundance of the minerals is not sufficiently taken into account, Osann attempts to bring out quantitative relations, within the families, by establishing certain types upon the basis of chemical composition.[2]

It is clear that if the quantitative element was not sufficiently expressed in forming the families discussed by Osann, he fails to remedy the defect. A logical subdivision of the families on a chemical basis would principally serve to point out the defects in this respect, and would really weaken rather than strengthen the system as a whole.

But the "types" set up by Osann are in no sense systematic divisions of the families. The "type" of this author is simply a chosen well-analyzed rock, differing in chemical composition from other rocks within its family, according to the adopted method of comparison. To a type thus established are referred other rocks of nearly identical chemical characters. But the types bear no definite relation to each other or to the family.

[1] *Tschermak's Min. und petr. Mittheilungen*, Bd. XIX, 1900, pp. 351–469, and Bd. XX, 1901, pp. 399–558.

[2] The author's standpoint may be sufficiently understood from the following statement: "Der Hauptmissstand der mineralogisch-structurellen Classification liegt darin, dass dem relativen Mengenverhältniss der wesentlichen Gemengtheile zu wenig Bedeutung zuerkannt wird, und es wird gerade die Hauptaufgabe der chemischen sein, in dieser Richtung ergänzend und vertiefend zu wirken." "So kann es sich bei dem hier unternommenen Versuch ebenfalls nur um ein künstliches System handeln, welches in erster Linie dazu bestimmt ist, das mineralogisch-structurelle zu ergänzen." *Ibid*, Bd. XIX, pp. 351–352.

They merely serve to show the chemical range found within the families so far as Osann's examination extends.

From the above statement it would appear that Osann has not, in reality, proposed a chemical classification in the systematic sense, and hence it is not desirable to enter further into the analysis of this elaborate discussion of the chemical varieties represented within the families of the Rosenbusch system.

This discussion of petrographic systems proposed during the nineteenth century will close with a review of three attempts to bring all known rocks into orderly arrangement. Not that the authors think to have formulated natural or logical systems, for that is expressly disclaimed by them. Yet in presenting these comprehensive arrangements of rocks, according to the light of the last decade of the century, these authors define and illustrate in a most effective way the present condition of systematic petrography.

Ferdinand Zirkel, 1893, 1894. — The second edition of Zirkel's *Lehrbuch der Petrographie* is the most comprehensive and complete description of all known rocks ever published, and it therefore represents the present status of the systematic science as a whole, better than any other work, and hence deserves careful consideration. But the fact staring the student in the face is that systematic petrography is still very largely an arrangement for convenience of description, and is not, in its entirety, a logical expression of relationships. Within the division of igneous rocks there is at least some attempt at system, but the other rocks confessedly defy logical treatment by any method as yet proposed.

The primary division of all rocks is on general geological grounds into four groups:

I. Igneous rocks — "Massige, eruptive Erstarrungsgesteine."
II. Crystalline schists.
III. Sedimentary crystalline rocks (not clastic.)
IV. Clastic rocks.

This division is clearly based on geological considerations,

and is chosen in place of the primary arrangement of the first edition because, as Zirkel points out, of inconsistencies and unnatural associations which resulted, some of which have been mentioned in this review. Contact metamorphic rocks are treated in connection with the igneous rocks which produced them. Fragmental igneous rocks are placed with the clastics.

In the systematic classification of igneous rocks Zirkel uses the bases of arrangement in the following order: (1) mineral composition; (2) structure; (3) age. The availability of chemical composition, alone, or in expressed combination with mineral constitution, is not discussed. The method of applying mineral composition for the classification of igneous rocks is that commonly used. Concerning this Zirkel remarks:

> In a mineralogical arrangement of massive rocks the following considerations are at present determinative: In the great majority of these rocks feldspars and other silicates resembling feldspars (such as nephelite, leucite, melilite) play the chief rôle, and therefore it is most natural to base the classification of such rocks upon the nature of these minerals, in accordance with existing nomenclature.[1]

This procedure results in placing *feldspar- or feldspathoid-bearing* rocks in one large group opposed to *feldspar-free* rocks. Whatever the facts may be as to the relative quantitative importance of different minerals in igneous rocks, it is clearly arbitrary to concede to any mineral the "principal rôle" where it is far subordinate to others. The result is a qualitative expression of mineral composition, bringing chemically unlike rocks together in many divisions.

In the descriptive portion of the *Lehrbuch*, igneous rocks are grouped under seven heads:

> I. Rocks with alkali feldspar and quartz or excess of silica.
>
> II. Rocks with alkali feldspar, without quartz or excess of silica, without nephelite or leucite.

[1] Für die mineralogische Gruppirung der Massengesteine sind zur Zeit folgende Erwägungen maassgebend: In der weitaus allergrössten Mehrzahl derselben spielen Feldspathe und andere feldspathähnliche Silicate (wie Nephelin, Leucit, Melilith) eine Hauptrolle und so scheint es am natürlichsten, die Classification der hierher gehörigen Gesteine auf die Natur dieser Mineralien zu begründen, was zugleich der bestehenden Nomenclatur entspricht. — *Petrographie*, Band I, p. 832.

III. Rocks with alkali feldspar, without quartz or excess of silica, with nephelite (haüynite) or leucite.

IV. Rocks with lime-soda feldspar, without nephelite or leucite.

V. Rocks with lime-soda feldspar and nephelite or leucite.

VI. Rocks without true feldspars, but with nephelite, leucite, or melilite.

VII. Rocks without either feldspars or feldspathoid.

Structure and geological age are applied by Zirkel under each of the mineralogical groups, as follows:

Granular rocks.

(No distinctions by age.)

Porphyritic and glassy rocks.

Pre-Tertiary.

Tertiary and recent.

The structural distinction is clearly in fact between (1) granular and (2) non-granular, the range in structure within the second division being by no means covered by the two terms porphyritic and glassy.

The use of age as a factor in classification of "porphyritic and glassy rocks" while it is not applied to the granular rocks is apparently more a recognition of the usage of the time, by which a duplicate set of terms has been provided for effusive rocks, than of any definite principle. The task of reconstructing the nomenclature of the science is still one from which the systematic petrographer shrinks.

The group of the *crystalline schists* established by Zirkel is not founded upon definitely stated principles, and is therefore not a systematic group. It is defined by enumeration of things belonging in it or excluded from it, and must be treated as a convenient expedient for purposes of rock description. But although this is true the crystalline schist group of Zirkel is no more unsystematic than the assemblages of other petrographers given the same name. It is then germane to the present discussion to state the actual course adopted in the *Lehrbuch*.

Zirkel includes in his group of the crystalline schists, and as its most important element, the pre-sedimentary gneisses, schists, etc., which cannot be inferred from their attitude to other rocks to be of igneous origin. Included with these are all rocks of the

same texture and composition demonstrably derived from sediments or occurring intercalated in the sedimentary series but not clearly of igneous origin. Excluded from the group under discussion are the primarily banded igneous rocks and the metamorphic derivatives of igneous rocks whenever that origin can be established, and whatever the process of change may have been. In other words the group includes the rocks below the oldest known sediments so far as they are not visibly eruptive or igneous and all later rocks of the same characters derived from sediments or of unknown origin.

This group then has nothing in texture or composition to distinguish it. Neither of the elements of the name has any restrictive significance. The group is geologically homogeneous only in case the schists of unknown origin are actually derived from sediments. If, as many suppose, a large proportion of the Archean gneisses, etc., represent igneous masses, metamorphosed or not, the group is not only heterogeneous from the genetic standpoint but causes the separation of identical things.

In the subdivision of the crystalline schists mineral composition is applied, the predominant constituent causing the reference of a rock to a certain group. The terms gneiss and schist are not defined.

The group of *crystalline, or non-clastic sedimentary rocks*, is heterogeneous in constitution as is apparent from a partial list of the rocks referred to it: ice, cryolite, limestone, opal, quartzite, porphyroid, iron ores, coals, diatomaceous earth. That such a group lacks the unity required in a systematic division, and that its descriptive name by no means covers the case, is apparent at once. It is confessedly a grouping for convenience only, and embraces, in fact, the remaining rocks after the other three have been established.

H. Rosenbusch, 1898.— A comprehensive discussion of rocks was issued in 1898, by H. Rosenbusch, entitled, *Die Elemente der Gesteinslehre*.[1] Although much less detailed than the *Lehrbuch* of Zirkel, this work is of much interest as expressing the views of

[1] Stuttgart, 1898, pp. 546 + 4.

one of the great German masters, almost at the close of the century.

Rosenbusch's primary division of rocks is into four great classes :

I. Eruptive rocks ("Eruptivgesteine").
II. Stratified rocks ("Die schichtigen Gesteine").
III. Crystalline schists.
III. Primary crust of the earth ("Erste Erstarrungskruste").

Concerning the first class, it is to be noted that Rosenbusch drops the term "massig," used for twenty-five years, as less appropriate—"weniger passend villeicht"—than *Eruptive*. In the further treatment of eruptive rocks Rosenbusch does not depart from the principles and methods of the last edition of the "*Physiographie der massigen Gesteine*," and there is, therefore, no occasion to repeat the analysis of that work already given.

The stratified rocks of Rosenbusch form a class under the general idea expressed by Lossen. It is pointed out by Rosenbusch that the character of the materials of stratified rocks is not so intimately related to the essence ("*Wesen*") of the mass as with eruptive rocks, and hence there is no corresponding firm basis for their classification.

Stratified rocks are divided into seven families, as follows:

1. *Precipitates*—including rock salt, gypsum, anhydrite, barite, etc.
2. *Psephites and Psammites* or clastic rocks.
3. *Siliceous rocks*—not clastic, partly chemical deposits, partly organic, partly of undetermined origin, *e. g.*, lydite, diatomaceous earth, sinter, etc.
4. *Carbonate rocks*—including limestone, dolomite, and impure calcareous rocks, loess, etc.
5. *Iron rocks*—including spathic iron, spherosiderite, brown hematite, bog ore, etc.
6. *Clay rocks*—including clay, clay-slate, phyllite, etc.
7. *Porphyroid.*

Appendix. Coals, etc.

In this arrangement Rosenbusch attempts no logical construction of anything which can be called a system. As he frankly admits, the porphyroids are metamorphic rocks, often associated with the crystalline schists, and as they were not

derived from sediments it is incorrect to place them in the stratified class. In the necessity for placing coals and other carbonaceous rocks in an *appendix* is further evidence that the arrangement under discussion is inadequate.

The Crystalline Schists are defined by Rosenbusch as alteration products of eruptive or sedimentary rocks. Both dynamic and contact metamorphism are recognized as effective in producing them. Rosenbusch further asserts that the changes have been entirely structural and molecular, and not chemical, hence by quantitative analysis of a metamorphic or crystalline schist one may arrive at a knowledge of the composition of the original rock, eruptive or sedimentary, from which that schist was derived. The designation *metamorphic rocks* is acknowledged to be appropriate.

The Crystalline Schists are treated under the following heads: (1) Gneiss, (2) Mica schist, (3) Talc schist, (4) Chlorite schist, (5) Amphibole and pyroxene rocks, (6) Serpentine, (7) Lime series, (8) Magnesian series, (9) Iron series, (10) Emery.

Concerning these groups Rosenbusch remarks:

> In most of these large groups of the Crystalline Schists, which are held together mainly through mineral composition, there are united rocks of fundamentally different genesis. Therefore they are not natural but rather artificial series. For the replacement of these artificial groups by natural ones there is lacking, at the present time, both necessary breadth of experience and maturity of judgment, from which the need for reform in various directions is evident.[1]

Believing that the natural classification of metamorphic rocks must develop by the historical method, with the increase of knowledge, Rosenbusch proposes, as a step in the desired direction, to apply the prefix *ortho* to the names of gneisses derived

[1] In den meisten dieser grossen Gruppen von Krystallinischen Schiefern, welche lediglich durch gleichen oder ähnlichen Mineralbestand zusammengehalten werden, sind genetisch grundverschiedene Gesteine zusammengefasst. Daher sind sie nicht natürliche sondern künstliche Reihen. Zur Umgestaltung dieser künstlichen Gruppen in natürliche fehlt zur Zeit noch einerseits die erforderliche Breite der Erfahrung, andererseits die Reife des Urtheils und damit das Bedürfniss nach Reform in weiteren Kreisen. — *Elemente*, p. 461.

from eruptive rocks, and *para* to those derived from sediments. The enumerated divisions of Crystalline Schists are not defined in a systematic manner, and even the terms *gneiss* and *schist* are given no definite meaning.

The fourth class of rocks advocated by Rosenbusch, on genetic grounds, *the original crustal rocks*, is considered by him as not certainly represented by any known rocks. But it appears to him probable that they possess the habit of the crystalline schists.

Johannes Walther, 1897. — An outline of a general classification of rocks upon a logical and consequent basis was presented to the Seventh International Congress of Geologists in St. Petersburg, in 1897, by Johannes Walther.[1] Although but an outline of a system this proposition deserves attention as the most consistent effort yet made to formulate a system of petrography co-ordinate in method for different classes of rocks.

Walther starts from the consideration that the growth of petrographic system in recent years has been very one-sided, a fact recognized by all. He believes that a natural arrangement of igneous rocks has been provided by petrographers of the modern school, while sedimentary and metamorphic rocks are still arranged upon old and partly incorrect bases. Aiming to secure a logical system, Walther formulates the following principles which he thinks should be observed in the classification of rocks:

I. The petrogenesis of recent deposits and the direct observation of actual processes are the fundamental principles of classification.

II. Every older rock has *primary* characters given it at its formation, and secondary ones derived by *diagenesis* or *metamorphosis*.

III. The derived characters may so change the type of the rock as to become "essential," while the primary characters become "accessory."

IV. In spite of this last condition only the primary characters should determine the principal groups of petrographic system.

V. Next to the primary lithologic characters the primary form of occurrence has a classificatory value. There must be distinguished, therefore, Unstratified, Stratified, and Dike rocks.

[1] "Congrès géologique international," *Compte-Rendu de la VII session, St. Pétersbourg, 1897*, p. 9 (issued in 1899).

VI. The characters derived by chemical diagenesis, or by contact and pressure metamorphism, serve for distinction of lesser groups.

VII. The altered rocks are to be placed with their original types.

The system proposed by Walther, in accordance with the stated rules, is in outline the following:

I. Mechanical Rocks. Composed of older rock fragments; divided by form and size of the fragments into 5 subgroups:
   1. Breccias: (*a*) Unstratified; (*b*) Stratified; (*c*) Dike form.
   2. Conglomerates: (*a*) Stream deposits; (*b*) Delta deposits; (*c*) Strand deposits.
   3. Moraines.
   4. Psammites — sands, more or less sorted: (*a*) Quartzose sandstone; (*b*) Arkose; (*c*) Olivine sands; (*d*) Iron ore sands, etc.
   5. Pelites — of minute particles: (*a*) Unstratified; (*b*) Stratified — fresh-water; (*c*) Stratified — marine.

II. Chemical rocks. Precipitates or sublimates.
   1. Calcium carbonate.
   2. Calcium sulphate.
   3. Sodium chloride.
   4. Haloid Salts ("Abraumsalze").
   5. Silica.
   6. Carbon.
   7. Ores.

Further divisions are made by occurrence — as Stratified, Unstratified, or in Dikes.

III. Organic rocks. Formed of the remains of animals or plants.
   1. Limestone: (*a*) Unstratified — Reef limestone; (*b*) Stratified — derived from plants (algæ); (*c*) Stratified — derived from animals.
   2. Silica: (*a*) Diatomaceous earth and land plants; (*b*) Diatomaceous earth with marine fossils; (*c*) Radiolarian earth.

IV. Volcanic rocks — Consolidated magmas.
   1. Lavas — Compact rocks: (*a*) Unstratified — deep-seated rocks; (*b*) Stratified — Effusive rocks; (*c*) Dike rocks.
   2. Tuffs — Magmas consolidated in small fragments: (*a*) Unstratified, in streams, not sorted; (*b*) Unstratified, subaqueous accumulations near vent — water tuffs; (*c*) Stratified, sorted according to specific gravity; originally inclined; traversed by dikes — tuffs about a land volcano; dry tuffs; (*d*) Stratified, alternating with marine deposits, without dikes; tuffs of sedimentation; (*e*) tuff dikes or chimneys.

In connection with these primary rocks the author mentions,

as examples, many of the forms derived from them by diagenesis or metamorphosis, but does not outline the system for discriminating and naming these alteration products. Some of the metamorphic rocks, such as gneiss and mica schist, may be formed from several primary rocks.

The proposition made by Walther is manifestly rather the work of a geologist than of a petrographer (as was pointed out by Brögger in discussion, when it was presented to the Congress). Like many discussions of principles concerned in the systematic problem, it is not sufficiently worked out to show a practical result, and does not fully test the adaptability of the chosen factors for petrographic system. But it seems to the writer that in this renewing of effort to treat the non-igneous rocks in logical systematic manner lies ground for hope that something more than an arrangement for convenience may develop during the early years of the twentieth century.

Returning to a consideration of the principles adopted by Walther, it may be remarked that the first one would be excellent if the processes of rock formation were all open to examination. Unfortunately, they are not so, in all cases. Many igneous rocks and nearly all of metamorphic origin have resulted from processes we cannot see in operation and can only imperfectly imitate in experiment. The fourth rule is not a necessary consequence of the facts stated under II and III. It is open to argument whether the processes which originally produced a rock are more deserving of recognition in petrographic system than the processes which have greatly or entirely changed the characters and perhaps even the composition of the original mass, making the rock now accessible to our studies.

As to rule V it can hardly be said to warrant the application made of it, in establishing the three divisions of unstratified, stratified, and dike forms for all kinds of rocks. Where the relations expressed by these terms have some genetic connection with the properties of the rocks they may perhaps be adaptable to classificatory purposes, but there is no logical reason for applying this principle in unqualified form.

The system of Walther seems specially intended to express the changes rocks undergo rather than their characters as now seen, and it is not apparent that the author had in mind the apt and logical analysis of the broad science of rocks which we owe to Naumann.

That the general treatment proposed by Walther for igneous rocks, in naming them volcanic, and making the primary division into unstratified, stratified and dike rocks, has many objections will be sufficiently clear from the preceding discussions of this review. The same is true of the assumption that there exists a satisfactory system for the classification of igneous rocks. The definition of tuffs as composed of magma consolidated in small particles certainly applies to but a small part of the pyroclastic deposits.

SUMMARY.

The science of petrography, the systematic and descriptive science of rocks, was first fairly outlined by von Leonhard (1823) and Brongniart (1827) through the distinction between the rock and the geological terrane, and the setting up of logical classifications for the former. Neither of these masters gave the science a name.

The systems of von Leonhard and Brongniart necessarily used the condition of ignorance concerning the character of many rocks as a ground for classification. With the increase of knowledge of rocks there have been many attempts to apply new information to systematic purposes. Since both the geological relations and the properties of rocks are highly varied many unlike systems have been proposed during the century, expressing individual opinions as to the relative importance or adaptability of principles for the end in view. Up to the present time, however, no comprehensive classification of rocks has been proposed which even pretends to be natural or logically consistent in all its parts.

When we view past petrographic systems, to judge as to how far they possess natural or artificial features, it is first of all to be noted that the system of Cordier is practically the only one starting from the conception that rock species are natural

units and that classification consists in the grouping by more or less artificial means of these fundamental units. Others have sought to make the system of rocks in some degree natural by applying geological factors of occurrence, or genesis, as bases of classification. The view is apparently held by some that in time there will be a comprehensive system expressing all important relations of rocks and that until that result is achieved all arrangements must be regarded as unsatisfactory and temporary.

It appears to the writer that those who hold this attractive and apparently philosophical view may not have in mind the distinction between the formal unit and the rock substance of that unit, or that distinction between the various cross-classifications of petrology and the one system of petrography, with which the nomenclature is specially connected.[1] The belief expressed by Lossen that "geological relations must be recognized as petrographical relations" and the assertion by Rosenbusch that "petrography is an historical science" illustrate this point.

If the system of petrography is to be hierarchical, as the writer believes it should be, the natural element in system is to be provided for in the judicious selection of broad geological factors so related to important characters of rocks that the completed system in the construction of which those characters have been used, will have a logical and appropriate co-ordination and sequence of parts. That this aim has not controlled in the past is evident from the following partial list of designations given to the rocks which are actually consolidation products of magmas: "Composite, crystalline-granular, and porphyritic" (Zirkel); "Non-clastic, composite, massive" (Zirkel); "Composite-simple" (von Lasaulx); Unstratified, Anogene, Massive, Plutonic, Volcanic, Eruptive, Igneous. Here are expressed a number of natural relations, to be recognized in the proper place, but only the last term refers directly to the relation most appropriate for petrographic system. It was not the fact that eruptive force was

[1] See "The geological versus the petrographical classification of rocks," by WHITMAN CROSS, JOUR. GEOL., Vol. VI, p. 79, 1898.

exerted to bring molten magmas to the sites of the rocks we study, but the fact of the molten condition which gave its stamp of common characters to the products of consolidation.

Arbitrary steps are necessary in the classification of such objects as rocks, exhibiting gradations in all directions. But that fact does not justify such artificial systems as many of those which have been reviewed. Among the most distinctly artificial systems are those of Cordier, Senft, and von Lasaulx; but scarcely less so, as regards igneous rocks, are those which, while using chemical or mineral composition as the basis of arrangement, use only a portion of the mass. For examples: some of the chemical classifications take only certain components into account; Fouqué and Michel-Lévy classify igneous rocks by the character of that variable portion of the magmas consolidating during the second period; Rosenbusch uses the phenocrysts only, in certain parts of his system.

The fundamental requirement that systems should be logical in construction, with consistent and consequent application of principles adopted, has been so commonly disregarded that a summary of instances in point seems unnecessary. Some of the most widely used systems of today are notably illogical as to criteria, as has been pointed out.

One of the most serious defects of modern classifications of igneous rocks is a matter of bad logic, and to this defect the writer wishes to allude once more. It is commonly admitted that the chemical composition of these rocks is their most fundamental characteristic, and many authors would apparently be glad to apply this character in classification. It is generally stated, however, that the chemical is represented by the mineral composition, and as the minerals are so prominent it is convenient to use them in system. But with no further discussion it has been the universal plan to use the minerals in so limited a qualitative way that they do not in fact express chemical composition except in a most crude and inadequate manner. This procedure is purely and simply illogical, if the intention be to represent chemical composition by the minerals of the rock.

That some factors have been introduced into classification in a manner that is quite unscientific seems plain. The age distinction is one of the factors thus abused. It has long been known that no general distinction separated pre-Tertiary and Tertiary igneous rocks. It may be that the average chemical composition of magmas erupted in successive ages has undergone some change; but neither the character of the change, nor, least of all, any special connection with the particular time limit in question, has been established. The assumption that igneous rock textures, such as the granular, porphyritic, or vitreous, are functions of geological form or place of occurrence, is known to be contrary to the facts displayed by the rocks. Both of these assumptions have been and are now used in rock classifications.

Stability of system is certainly desirable, within the bounds of reason. But it is also self-evident that a system of artificial character, in which the subjective element is dominant, can be permanent only by universal consent of petrographers, and such consent is not to be expected. It is a matter of experience that genetic theories have made systems into which they have been introduced very unstable and impossible of general adoption. The danger of using hypotheses in classification has been well characterized by von Cotta, somewhat as follows: Geology is a particularly alluring field for premature attempts at the explanation of imperfectly understood facts; indeed, such attempts are almost unavoidable in the study of this science. When one considers hypotheses simply as such, *i. e.*, as stimulants toward their possible demonstration, then they are not harmful; the danger lies therein that one may believe them already proven and rest contented.[1]

The danger pointed out by von Cotta has been illustrated in the classification of igneous rocks by such able men as von Richthofen, King, and Rosenbusch. As regards the interior of the earth, whence the molten magmas come, we cannot as yet be sure that what we regard as a law today may not be relegated to the status of a theory or even of an hypothesis tomorrow.

[1] B. von Cotta, *Gesteinslehre*, 2d ed., 1862, p. vi.

The genetic theory has its proper field of great usefulness in the department of petrology dealing with petrogenesis. Ultimately we may hope and expect that genetic relations of igneous rocks may be available for a more natural classification than is now feasible.

Any system of classification should be broad and thorough enough to include all the objects which it professes to deal with. But the authors of many systems outlined in this review have been obliged to resort to the expedient of *appendices* to bring in rocks not otherwise provided for. Such a necessity is, at once, evidence of the inadequacy of the criteria guiding the authors of such systems.

Even in the class of igneous rocks, propositions for chemical and mineral classifications do not fully recognize the systematic importance of some of the relatively rare constituents. Chemical systems which consider all igneous rocks as mixtures of silicates, or reject magnetite as extraneous, are not comprehensive. Similarly, the schemes which do not provide for the due recognition of titanium minerals, corundum, apatite, sulphides, etc., as important constituents in some cases, are inadequate, even for present uses, and certainly do not provide for future needs which can be clearly foreseen.

In conclusion, the status of systematic petrography at the close of the nineteenth century may be summarized as follows:

1. There is as yet no comprehensive and properly systematic classification of all rocks. All so-called systems exhibit portions in which the rocks are treated in an unsystematic manner, for convenience of description and discussion. The grand divisions are not treated by similarly logical and definite methods.

2. Rocks of igneous origin have been much more thoroughly investigated than others and they have received correspondingly more definite and systematic classification. The factors used in systematic construction pertain to genesis, age, and characters.

a. The origin of the great range in chemical composition exhibited by igneous magmas, expressed in theories of magmatic differentiation, is an underlying factor of much importance in

the system of Rosenbusch, and is also seen in the desire to recognize consanguinity of the magmas of petrographic provinces, as partially worked out by Iddings and Brögger. The availability of such factors in petrographic system is doubted by many authorities.

b. While the distinction of older and younger series of rocks through different sets of names is still found in the German and French systems there is practical unanimity of opinion that the real differences between the rocks are much less fundamental than was supposed. In America, Great Britain, and elsewhere, this distinction is held to be unwarranted.

c. The chemical and mineral composition of igneous rocks and their textures are characters used as means of classification in present systems. Chemical composition *per se* is used, but only by considering a portion of some rocks, and hence fails to provide an adequate system. The broad chemical divisions used by some authors are vague and overlapping.

Mineral composition is commonly assumed to represent the fundamental chemical constitution and to be, therefore, a convenient and practicable means of expressing the latter. In practice the qualitative method of applying mineral composition in existing systems destroys its effectiveness as expressing chemical composition.

Structure is variously used in present systems. It is acknowledged to be the product of conditions, and not dependent in marked degree upon mineral development. When applied as a primary factor in classification (as by Rosenbusch) it separates things which are similar in more fundamental characters, and on this ground some authorities believe that structure should be applied in classification after the other characters named.

3. The rocks which have formed upon the surface of the earth by the destruction of older rocks may be viewed from so many standpoints, as regards the origin of materials, agencies of transportation, relations to the earth or to other rocks, characters of materials, and processes of induration, that no consistent arrangement of these objects, deserving the name of a petro-

graphic system, has been proposed. In the existing arrangements the confusion of correlating various cross-classifications into one whole is quite evident.

4. Metamorphic rocks, including all such in which the derived characters are more prominent than the original ones, defy systematic treatment at the present time. Since they have been formed from all kinds of original rocks, by many different processes, and at many sites in the earth's mass, there are many standpoints from which they may be considered, and their classification is a complex problem. Among the facts most difficult to recognize in system are the close resemblance or identity of metamorphic products from originally different rocks, and the similar correspondence between certain secondary and primary rocks. The proposition of Walther to classify all metamorphics with the masses from which they were derived is thus impracticable at the present time, even if it be thought desirable. In relation to this class of rocks systematic petrography is in the condition that its arrangements are tentative, awaiting new knowledge concerning the genesis and essential characters of the objects.

The review of the development of systematic petrography given in the preceding pages has been mainly a discussion of comparatively comprehensive arrangements or systems which have been proposed. It is, of course, true that these systems are but correlations of ideas from many sources, and a complete history of the subject would give to important discoveries of fact and to critical or creative suggestions their due weight in influencing the development of systems. But such influence is difficult to trace, and to have attempted such a history would have involved the expenditure of much more time than the writer could devote to the subject. For this reason a large number of important essays, bearing upon certain features of classification or devoted to discussion of principles, have been left unnoticed because they were not accompanied by general

systematic propositions. Among the essays thus disregarded are notable ones by Rosenbusch, Brögger, Becke, Michel-Lévy, Teall, Iddings, Spurr, Turner, and many others.

The telling effect of searching investigations touching controverted points of fundamental significance and of the judicial remarks of those who have carried out such studies is often much greater than either author or reader is aware. In the course of time the influence exerted by a succession of investigations becomes evident in some proposition for the revision of classification. Petrography has thus come to its present condition by a steady natural evolution, and its future growth must undoubtedly follow the same course.

WHITMAN CROSS.

AN ANALCITE-BEARING CAMPTONITE FROM NEW MEXICO.

DURING the summer of 1899 the writer was a member of the field class of Professor R. D. Salisbury, of the University of Chicago. The party visited the Grand Canyon of the Colorado, stopping on the way at several localities of interest. The first halt was made at Las Vegas, New Mexico, where Miss Inez Rice, a member of the class, guided the party to the butte which forms the subject of this paper. I take pleasure in acknowledging my indebtedness to Professor Salisbury for assistance in the field, and to Miss Rice for suggestions on the general geology of the region. The petrographic work was done in the laboratory of Columbia University, and thanks are due to Professor Kemp for much kindly advice and assistance. Special thanks are also due to Dr. F. Bascom and to Dr. H. S. Washington, for reading this paper and for suggestions concerning it. The analysis was very kindly contributed by Mr. George A. Goodell, of the College of Physcians and Surgeons; the photograph which forms the accompanying illustration (Fig. 1) was obtained through the courtesy of Mr. K. M. Chapman, of Las Vegas. Special thanks are due to both these gentlemen.

The Las Vegas region exhibits the general geology and physiography typical of the eastern border of the Rocky Mountains. In it are represented the two great geographical provinces, the Great Plains and the Cordilleran region. These two geographical districts are in close correspondence with the geological structure.

The Cordilleran section consists of a doubtfully Archean floor, upon the base-leveled surface of which Carboniferous limestones were deposited. This represents an overlap beyond the Cambrian which underlies the Carboniferous farther north. Unconformably above the Carboniferous, and situated along

the line bounding the two geographic regions, are the Red Beds of Permo-Triassic age, with their associated gypsum deposits. The relation of physiographic form to geologic structure is most excellently exhibited. The hard granitic rocks stand out as rugged peaks, with occasional gentle slopes where the Carboniferous limestones are left on their flanks. The Red Beds represent the softest rock of the region, and the position of this outcrop is marked by a valley.

FIG. 1.—View of Camptonite butte, Las Vegas, New Mexico.

The contrast between the Cordilleran region and the Great Plains is both structural and physiographic. The latter region is underlaid by the Dakota and Colorado formations, with occasional remnants of the Montana and Laramie. Except near the mountains, the Cretaceous formations are nearly horizontal, but there they are upturned. Throughout Colorado and northern New Mexico, the outcrop of the Dakota sandstone forms a series of ridges locally known as "hog-backs." Las Vegas is situated at the eastern base of one of them.

About four miles slightly north of east of Las Vegas there is a little butte of igneous rock of exceptional interest. The structure of the rock and its occurrence indicate that it was intruded into the Cretaceous beds at a considerable depth, though it now stands somewhat above its surroundings.

The rock is probably to be referred to the group described by Professor Pirsson[1] as "the analcite group of igneous rocks," and no similar rock has hitherto been described from this region. Similar masses are mentioned in the Elmoro folio, and termed "lamprophyres," hence it is probable that future investigation will bring to light other related intrusions.. No elaeolite syenite nor other rock that could be related to these lamphrophyric intrusions has yet been found; hence the relationship of the rock and the magmatic history of the group to which it belongs, remain as problems to be studied in connection with the further investigation of the region.

The rock is medium grained, of a general gray appearance, with large crystals of hornblende and augite which can readily be seen with the naked eye. In the predominating phase of the rock, these crystals are about .8^{mm} in length, but in occasional segregations they reach a length of as much as 1^{cm}. These ferro-magnesian minerals lie in a gray groundmass which on microscopical examination proves to be mostly plagioclase.

In thin section the rock is seen to be porphyritic, with phenocrysts of augite and of hornblende, occurring in equal amounts, and of rarer biotite. The groundmass consists of a network of plagioclase, with an isotropic substance which is probably analcite, filling the interstices between the plagioclase laths. Magnetite, ilmenite, and apatite are also present.

The pyroxene is always idiomorphic, occurring in large phenocrysts and also to a small degree in the groundmass. It is a pale greenish-violet, normal augite, and is very faintly pleochroic. The cleavage is well defined. Some of the porphyritic crystals show a slight zonal structure. Twinning is very common and usually the twinning plane is $\infty P\frac{1}{\infty}$ (100). Certain complicated intergrowths also occur, which probably also represent twinning, the twinning planes being $-P\frac{1}{\infty}$ (101) and P_2 (122) (Fig. 2).

[1] L. V. Pirsson, Jour. Geol., Vol. IV, 1896, pp. 679–690.

Intergrowths of augite and hornblende are common, and so are occasional inclusions of augite in hornblende (Fig. 3).

The amphibole is idiomorphic, occurring only as a phenocryst. It is of the basaltic hornblende type. The pleochroism is very strong, **c** and **b** = deep brown, **a** = pink. The terminal faces are usually lacking. These phenocrysts exhibit the characteristic cleavages of hornblende. In a few slides a very small amount of secondary hornblende was found associated with the augite, but the prevailing hornblende is certainly an original constituent.

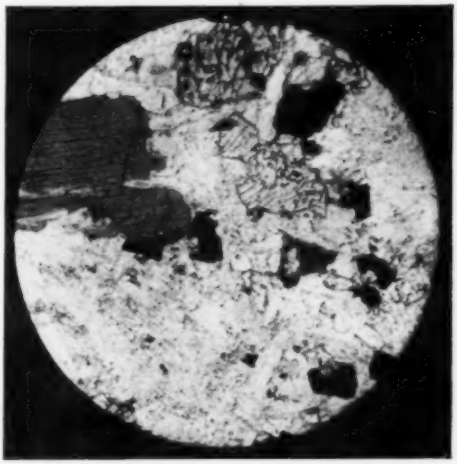

FIG. 2.—Twinned aggregate of augite.

Mica occurs in small quantity, as irregular shred-like phenocrysts. It is a very pleochroic biotite, changing from brownish-black to reddish-brown.

The feldspar occurs in the groundmass, as lath-shaped, polysynthetically twinned crystals. They form an interlocking network which is difficult of interpretation; a number of readings of extinction angles on the *P* face varied from 15° to 35°, indicating a plagioclase rich in lime (bytownite or anorthite). The presence of this plagioclase is further indicated by the high lime percentage of the analysis.

Lying between the laths of feldspar is an isotropic substance which appears to be analcite. It occurs in such small areas and is so thoroughly mixed with the groundmass that determinations of it were necessarily imperfect. In one instance it exhib-

ited the cubical cleavages of analcite. The rock was fresh and this mineral was undoubtedly of primary origin, being apparently the last to crystallize and filling all interstices. The larger grains are free from inclusions, but are sometimes surrounded by rings of magnetite and ilmenite grains; the smaller grains often contain a fine black dust suggestive of leucite. This structure appears to be identical with that described by Mr. Cross in the case of an analcite basalt.[1]

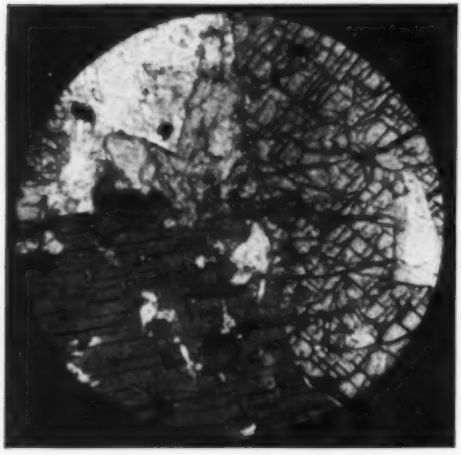

FIG. 3.—Intergrowth of hornblende and augite, with inclusions of augite in hornblende.

Magnetite and ilmenite are abundantly distributed in large crystals. Apatite occurs in the form of elongated prisms with truncated corners, and is common throughout the groundmass.

Very little alteration could be seen in any of the constituents. As already mentioned, very small amounts of secondary hornblende occur, derived from the augite. The plagioclase is occasionally slightly sausuritized, and small quantities of secondary epidote are occasionally found. The rock as a whole is, however, remarkably fresh.

The most noted district for rocks of this class is the neighborhood of Lake Champlain, where they have been made known principally through the work of Professor Kemp.[2] The writer

[1] WHITMAN CROSS "An Analcite-basalt from Colorado," JOUR. GEOL., Vol. V, 1897.

[2] J. F. KEMP, "Trap Dikes of Lake Champlain," *Bull. 107, U. S. Geol. Surv.*

has compared the slides of the Las Vegas rock with those from the Champlain region, and also with those from Campton Falls,[1] from Whitehall and Fairhaven, Vt.,[2] and several neighboring localities; and with a series from the Black Forest in Germany. When all these camptonites were studied and compared with the Las Vegas rock, a marked difference in texture was seen. The Las Vegas rock is coarser grained, the phenocrysts more abundant, and there is a less marked difference in size between phenocrysts and groundmass. This is what might be expected since the eastern rocks occur in dikes, and the Las Vegas one in a stock. The eastern rocks are all considerably altered, containing calcite, serpentine, delessite, and secondary analcite. The Las Vegas rock is remarkably fresh. This comparison gives strong indirect evidence of the primary character and analcitic nature of the isotropic substance; the rock is too coarse-grained for it to be a glass and too fresh for it to be a secondary product.

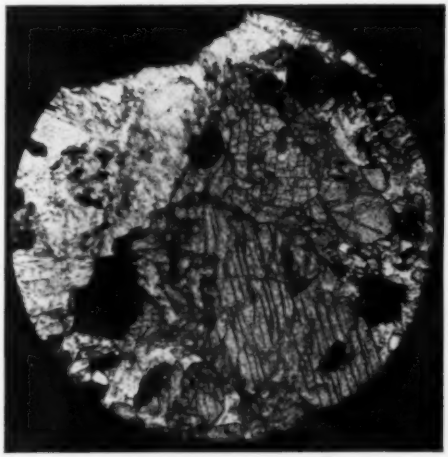

FIG. 4.—Typical section of the Las Vegas Camptonite, showing phenocrysts and groundmass.

The term "Camptonite" is commonly applied to the plagioclasic lamprophyres, in distinction from minette and vogesite which are orthoclasic. Common usage[3] has restricted the term Camptonite to the lamprophyric plagioclase rocks with horn-

[1] Described by J. W. HAWES, *Amer. Jour. Sci.*, ser. 3, Vol. XVII, p. 148.

[2] Described by J. F. KEMP, *Amer. Geol.*, Aug., 1889.

[3] F. BASCOM, *Nineteenth Ann. Rept. U. S. Geol. Surv.*, Part III.

ANALYSES.

	I.	II.	III.	IV.	V.	VI.
SiO_2	44.48	38.45	41.94	45.76	45.11	42.08
Al_2O_3	20.43	19.68	15.36	20.48	19.67	20.88
Fe_2O_3	9.72	4.01	3.27	1.99	4.32	6.77
FeO	2.18	11.15	9.89	4.18	8.57	3.17
CaO	10.35	9.37	9.47	11.57	10.45	12.48
MgO	5.51	6.65	5.01	8.50	5.65	6.85
TiO_2	.57	....	4.15	....	0.21	....
MnO	....	trace	0.25	....	....	....
K_2O	1.59	1.72	0.19	0.80	0.64	0.44
Na_2O	3.61	2.77	5.15	3.56	3.87	3.37
Loss on ignition	3.21	....	3.29	2.80	....	....
H_2O	....	1.49	....	....	0.17	3.18
CO_2	....	4.82	....	....	....	....
P_2O_5	....	....	....	....	0.25	....
Total	101.65	100.11	100.44	99.64	100.07	99.22

I. The Las Vegas rock.

II. Camptonite from Campton Falls, N. H. Published in *Bull. 148, U. S. Geol. Survey*, p. 67.

III. Camptonite from Campton Falls, N. H. J. W. Hawes, *Am. Jour. Sci.* Ser. 3, Vol XVII, p. 150.

IV. Gabbro from Rosswein, Saxony. Landwirthsch Versuchs station 40, 1892.

V. Diorite from Lindenfels, Hesse Darmstadt. Chelies & Klemm, *Erläuterung zur Geologischen Karte von Hesse*, 1896.

VI. Basalt, middle flow, Carlsbad, Bohemia. *Jahrbuch der Königlich Kaiserlichen Gesellschaft Kunstausstellung*, Vol. XL, p. 345, 1890.

blende as the principal ferro-magnesian mineral; augite camptonite is applied to those in which augite equals or exceeds hornblende; analcitite to those containing primary analcite. Rosenbusch's latest definition (1901) includes augite as an essential constituent of a camptonite, thereby departing from the original type of Hawes in which hornblende predominated.

In the case of the Las Vegas rock hornblende and augite occur in approximately equal quantities. Since the tests for analcite were not conclusive, the rock could not be called an analcitite. It seems most logical to regard equal amounts of hornblende and of augite as distinctive of a camptonite, restricting augite camptonite to those with augite in excess. The Las Vegas rock can thus most logically be termed an analcite bear-

ing camptonite. I am indebted to Dr. Bascom for suggestions on nomenclature.

The accurate recalculation of the analysis proved impossible, owing to the combination of minerals containing the same oxides. The high Na_2O is a strong indication that the isotropic constituent is analcite, and this is further indicated by the optical character of the plagioclase; it is near the anorthite end of the series, hence, has low Na_2O. Microscopically hornblende, augite, and plagioclase are present in approximately equal amounts.

Analyses two and three are typical camptonites, and it will readily be seen that the Las Vegas rock is close to them chemically. Analyses four, five and six are of rocks of other groups which are also similar chemically. The likeness of the last three was kindly suggested by Dr. Washington.

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HOLYOKEITE, A PURELY FELDSPATHIC DIABASE FROM THE TRIAS OF MASSACHUSETTS.[1]

In the monograph of the three river counties in Massachusetts,[2] the writer described a "white trap" which occurs only in scanty fragments in a bed of agglomerate interstratified in the sandstone, a few feet above the surface of the great Holyoke trap sheet at the east foot of Mount Tom, and a few rods north of the station of the electric road going up onto the mountain. The small angular fragments of the volcanic rock are scattered rather distantly in the calcareous red sandstone, and seem closely like a white, horny limestone spotted with chalcopyrite. They include fragments of the coarse sandstone below the Holyoke trap sheet, up through which they must have come, and these inclusions are much coarser than the sandstone in which they are included. The weathered surfaces show the rock to be finely amygdaloidal, and acid brings out in the interior the same structure which can indeed be seen, by attentive study with a lens, on a freshly broken surface. A few grains of yellow ore appear here and there in the body of the rock and in the round cavities, and rarely the reflection of a twinned plagioclase lath is visible.

The thin section shows so exactly every structure of the diabase except those dependent upon the presence of iron in form of magnetite and augite that one cannot help associating it closely with the adjacent Holyoke sheet, as I have formerly done by calling it a "white trap." Even the presence of much chalcopyrite is characteristic. Under the microscope the texture is exactly that of the trap of the large sheets minus the augite. It is especially like the superficial portion of the Deerfield sheet exposed at Cheapside.

There is an ophitic network of very fine plagioclase needles

[1] Published by permission of the director of the United States Geological Survey.

[2] *Monograph XXIX, U. S. Geol. Surv.*, 1898, pp. 365–474.

of two sizes, both elongate blades with ragged ends and irregular sides; the finer about 0.03^{mm} long; the latter having sometimes quite regular crystalline outlines. Scattered in this network are distant feathery groups of plagioclase crystals of first consolidation which are just visible to the eye. One of these larger crystals cut parallel to M (010) showed the optical figure of albite.

All these feldspars are lightly dusted with blades and grains of a secondary mineral of low polarization, probably zoisite. And there is a very little granular limonite scattered through the rock, but no accumulation of it, or appearance of any chloritic mineral to indicate the former presence of magnetite and augite or hornblende. There are no brightly polarizing blades that could be referred to a colorless bisilicate.

As in the peculiar red diabase from Cheapside, near Greenfield, described in the monograph[1] above mentioned, the small round steam cavities are lined by a secondary growth of albite in fresh limpid crystals.

There are other fragments associated with the Holyokeite which are black, aphanitic, and show under the microscope a similar texture, but contain large spots of a green chloritic mineral.

The chemical composition of the rock is shown by the following analysis I, by Mr. Hillebrand.

If we follow the calculation of the analyst and assign the sulphur to 0.40 chalcopyrite and 0.06 per cent. pyrite, and then calculate the phosphoric acid as apatite, the titanic acid as ilmenite, the potash as orthoclase, and assign the carbonic acid to the magnesia and most of the calcium, we shall account for 30 per cent. of the analysis.

It is interesting that the remaining 70 per cent. has the composition of an albite of exceptional purity, and the only feldspar determined in the slide was albite.

SiO_2 - - -	67.89
Al_2O_3 - -	20.87
Na_2O - - -	11.24
	100.00

[1] *Loc. cit.*, p. 431.

	I.	II.	III.
SiO_2	53.83	60.13	51.78
Al_2O_3	16.36	20.47	12.79
Fe_2O_3	0.89[1]	1.04	3.59
FeO		.72	8.25
MgO	.13	1.15	7.63
CaO	9.81	2.59	10.70
Na_2O	7.89	9.60	2.14
K_2O	1.58	1.06	0.39
H_2O-	.15	.....	.63
H_2O+	.36	.....	.....
TiO_2	.86	trace	1.41
ZrO_2	.02	.....	.....
CO_2	7.47	3.44 (Ignition, includes H_2O)	.....
P_2O_5	.11	.....	.14
S	.17[2]	.....	.....
MnO	a little lost	trace	0.44
BaO	none	.....	.....
SrO	none	.....	.....
Li_2O	none	.....	.....
CuCu	.14[2]	.....	.....
	99.77	100.20	99.89

I. Analysis of Holyokeite made by Mr. Hillebrand, of the United States Geological Survey.

II. Analysis by Dr. H. S. Washington of the acid dyke in the Connecticut Trias, described by Mr. E. O. Hovey and mentioned below. *Specific Gravity* at 11° C = 2.63.

III. Analysis of the normal Triassic diabase of West Rock, New Haven, by Mr. G. W. Hawes. *Am. Jour. of Sci.*, III, IX, 186, 1875.

[1] The figure here given (0.89) includes not only ferric and ferrous iron, but also that in combination with sulphur, as (Cu FeS_2) and possibly a little FeS_2. Because of the sulphide FeO could not be estimated. (Hillebrand.)

[2] Taking the Cu as a basis the sulphides figure out 0.40 per cent. $CuFeS_2$. I cannot say that there is any FeS_2 present. The mass of the sulphide seems certainly to be chalcopyrite. (Hillebrand.)

The whole rock will then contain, roughly speaking:

Apatite	0.23
Dolomite	0.52
Calcite	16.42
Orthoclase	9.41
Albite	70.25
Ilmenite	1.63
Chalcopyrite	.40
Pyrite	.06
	100.00

This ignores the water which might have been calculated, perhaps, as kaolin, since there is no visible chloritic mineral or zeolite. It ignores also a third of a per cent. of CaO, which now forms calcite, and which with the rest of the calcium was present in the original rock, perhaps for the most part, as anorthite; that combined with the albite formed several intermediate varieties of plagioclase.

This calcium may have been present in part as a sahlite. In the latter case it might have been called a sahlite-diabase, but in a sense very different from that in which the word has been used by Törnebohm for a diabase in which the sahlite is quite subordinate to the abundant augite. The rock in which the fragments are embedded is, however, so calcareous that some part of the calcite may have been introduced into the amygdaloidal cavities from without.

The leucophyr of Gümbel is, as compared with diabase, "a remarkably light-colored rock with saussuritic feldspar, pale green augite (without hornblende and rarely with red-brown augite), with a chloritic constituent in large quantity and tabular ilmenite." This seems to me quite plainly an altered diabase, and different from this non-ferruginous rock.

The only similar rock that has been described from the American Trias is the acid dyke discovered by Mr. E. O. Hovey in the new cut on the Shore Line Railroad, in the eastern part of New Haven, provisionally referred by him to keratophyr. It is distinctly different from the type described here.[1] It is brick-red like the Cheapside trap, or grayish like the second variety described above, which accompanies the white trap.

It is largely feldspathic and the ferro-magnesian minerals are absent, but chlorite is present in considerable abundance, and the fields of chlorite and calcite "for the most part have definite outlines which strongly suggest the original presence of phenocrysts of pyroxene (augite) in the rock." Mr. Hovey remarks that spherocrystalline structure was observed in some places. This may have been the structure that I have interpreted above

[1] *Am. Jour. Sci.*, ser. 4, Vol. III, p. 287, 1897.

as a growth of secondary albite in steam holes. This suggestion depends upon a comparison with material of exceptional excellence from Cheapside where the whole process could be followed and where the perfect crystals of albite could be isolated and determined in heavy fluid. The chemical differences between the two rocks are many, as may be seen by comparing the analyses given above. In the matter of SiO_2 and Al_2O_3, the Holyokeite is intermediate between the keratophyr of Hovey and the normal diabase.

The minute quantity of iron (not enough to satisfy the S and TiO_2) and magnesia, show that there can scarcely have been a trace of augite or sahlite present in the Holyokeite, while the keratophyr may have contained much bisilicate. Finally the discrepancy in the CaO is decided, even after saturating the CO_2, and would demand, considering also the smaller amount of SiO_2, a somewhat larger proportion of anorthite in the Holyokeite, while the larger amount of K_2O would demand for it a greater amount of orthoclase or anorthoclase.

The Holyokeite may then be looked upon as representing a limiting form of the diabase series where the bisilicates are wholly wanting.

B. K. Emerson.

THE LANDSLIDES OF MT. GREYLOCK AND BRIGGSVILLE, MASS.

A STUDY of the topographic and geologic maps of Mt. Greylock will show where, theoretically, landslides would be most likely to occur. Both the large and small slides on this mountain are where, in theory, they should be. These slides are typical of one class, and the one at Briggsville of another.

The scarring of the mountain side by this agency is a very striking feature of the landscape, as one looks west from the Hoosac range and from the Hoosic valley for two or three miles on either side of Adams. The eastern side of Greylock is the steepest on the mountain, rising 1400 feet in two-fifths of a mile. It was on this slope, the base of which is about two miles west of Adams, that the land slipped. In all there are three large and eight small landslides within a mile.

The facts concerning the conditions at the time at which the landslides occurred were gathered largely from persons in the vicinity of Adams, but especially from Mr. C. O. Gould, whose farm is located at the foot of the main slide. The facts are as follows: During July and August, previous to August 20, 1901, the date on which the slides occurred, 12.92 inches of rain fell, being 5.8 inches above normal. At about three o'clock on the afternoon of the 20th a very heavy rain, spoken of usually as a cloudburst, began to fall, and lasted until seven o'clock. The record for this period at Williamstown (on the other side of the mountain) is 2 inches; at Mt. Tom, 3.42 inches. The water in the creek at the foot of the mountain rose very rapidly until it was as high as it had ever been noticed. When the slide occurred the stream became "a torrent 75 to 100 feet wide, 10 feet deep, and filled with trees." Five or six acres of the farm were covered with sand and bowlders, some of the bowlders being 4 feet in diameter.

Mt. Greylock, showing landslides. (The steepness is not well shown.)

The middle slide came first, and the large one to the north next. The time of the occurrence of the large slide to the south was not noticed, but all must have occurred within a few minutes of each other.

The mountain in this place is made up, above, of a mica schist (Greylock schist), and, below, of a rotten micaceous limestone (Bellowspipe limestone). The slope is covered with loose talus and earth, upon which is a sparse growth of trees.

The north landslide occurred at the road near the top of the mountain, where the slide is about 50 feet wide, and extends for 1500 feet down the mountain side. It gradually widens until at the base it is about 200 feet wide.

From the above it will be seen that all of the conditions were favorable for a landslide; the steepness of the slope, the fissile character of the rock, the loose material of the mountain-side wet with the unusually heavy summer rain. All that was needed to cause a slipping of this loose material was a large quantity of water to add to the weight of the mass, and at the same time act as a lubricant. The destructive force of the water was caused by the natural drainage of an unusually heavy rain, and by the water brought down and squeezed out of the mass which slid down the mountain-side. There is no evidence that a dam was formed. In the ravine through which the water flowed the water was in places 25 feet deep, as shown by the overflow.

The removed material was not piled up with a backward slope toward the mountain, as is usually the case, the great quantity of water being sufficient to remove a large part of the débris so that much of the rock and earth was carried to and deposited in the valley below.

The landslide at Briggsville is more complex. Back of the woolen mills of Strong, Hewatt & Co., and on the west bank of Beaver Creek, one sees stratified blue clay tilted at all angles from a 90-degree to an almost horizontal position. A pier is raised 4 feet and tilted to the west, and the dam to the north of the mill is raised several feet on the west side. The tilted area

Mt. Greylock, showing landslides. (The steepness is not well shown.)

is about 325 feet long and 33 feet wide. To the west of this is an excavation from which the material in the creek bed was derived. This cavity is some 320 feet in length from east to west, and about 30 feet lower than the original surface.

The history of the phenomena is as follows: During 1895 a spring, called a "geyser" in this vicinity, broke out with considerable force. The water contained a great deal of sediment, (finely divided blue clay) which was at first "as thick as pea

Topographic map of Greylock with position of the three large landslides.

soup" and contained large quantities of decayed roots. The muddy water was of sufficient volume to so contaminate the water of Beaver Creek as to render it unfit for the use of the Windsor Print Works.

The land above the spring gradually sank as the bank was undermined and with each subsidence of the surface the spring moved back toward the high bank to the west. Before the sinking occurred growing trees sank beneath the surface, in an upright position, and poles could be driven down several feet with little effort. During a flood in March, 1901, the bridge pier was tilted, the dam was raised, and the clay appeared in the creek bed. This land continued to rise for several months.

The explanation is as follows: The sediment in the water was produced by the breaking and fracturing of the clay bank,

which fracturing so loosened the clay that it could be carried away in suspension. This continued until a large quantity of clay had been removed from a stratum immediately underlying the surface sod. The most evident explanation for the slipping of the clay and its uptilting in the stream bed is that a stratum of blue clay rested on an inclined plane which was rendered slippery by the water of the spring. This stratum was separated from the surface sod by the washing away of the clay between them. When it slipped it was stopped either by the former rock bank of the stream or by some other obstacle, the slope and weight being sufficient to push the clay up from the stream bed and to raise with it the pier and part of the dam.

After the last slipping the muddiness of the water was greatly lessened showing that the movement of the ground had almost ceased. Since then, however, the amount of sediment in the water has increased, indicating that a further fracturing is in progress.

H. F. CLELAND.

WILLIAMSTOWN, MASS.

NIAGARA METEORITE.

In the winter of 1900 I was informed by Mr. Vennor, a young mineral collector of Rochester, N. Y., that he had seen in the possession of one of his friends, now living in this city, what he supposed to be a small iron meteorite, which had been picked up on a ranch in North Dakota, some years before. After some persuasion Mr. Vennor succeeded in getting his friend to permit me to examine the specimen, which I saw at a glance was a meteorite with marked octahedral cleavage where it had been broken, and finally purchased it for Ward's Natural Science establishment.

This meteorite, which belongs to the siderite class, was found two miles southeast of Niagara, Forks county, N. D., in the early part of August, 1879, by Mr. F. Talbot, the son of the lady from whom Mr. Vennor obtained it for me. Mr. Talbot was making a collection of the various rocks and minerals in his neighborhood, and in his search for these discovered the above meteorite on the ranch owned by his father. As Mr. Talbot has since passed away, the specimen had been retained in his family rather as a keepsake in remembrance of him than as a visitor from outer space.

When I received the meteorite it weighed 115 grams and was about $30 \times 40 \times 50^{mm}$ in dimensions. It was very much oxidized, of a brownish-black color, and showed no trace of the original crust whatever. In sawing it we succeeded in getting but three sizeable pieces, as it crumbled into small fragments from 2 to 4 or 5 grams in weight in cutting. The largest piece obtained of the unoxidized iron suitable for etching weighed 26 grams and is now in the Ward-Coonley collection of meteorites. The only other piece suitable for etching weighed 17 grams and is in the British Museum collection. The largest fragment from the crumbled portion of the iron was a fairly good tetrahedron, $24 \times 23 \times 15^{mm}$ in its greatest diame-

ters, and weighed 18 grams. This fragment showed bright plates of taenite on two of its cleaved faces. This feature was likewise shown on a number of the smaller fragments.

On etching the two pieces composed of the unoxidized iron, its octahedral structure was strongly marked in the Widmanstätten figures, the kamacite plates being somewhat broad with a second series of markings of hair-like lines upon them about the size of the Neumann lines on the Braunau iron.

Mr. J. M. Davison, of the Reynolds Laboratory of the University of Rochester, kindly made the analysis of this meteorite for me, and found it to be composed of

Fe	92.67
Ni	7.37
CO	0.13
	100.17

Specific gravity 7.12.

From its close proximity to Niagara, we will designate the siderite the Niagara, Forks county, N. Dakota Meteorite.

H. L. PRESTON.

ROCHESTER, N. Y.

ON THE SKULL OF NYCTODACTYLUS, AN UPPER CRETACEOUS PTERODACTYL.

ELSEWHERE I have published a brief description, with a restoration,[1] of an unusually complete specimen of *Nyctodactylus*, recently collected by my assistant, Mr. H. T. Martin, in western Kansas. At the time this restoration was made, the skull was lying in its original matrix, with its palatal surface uppermost. On account of its extreme delicacy, it was thought best then not to attempt its removal. This, however, has since been done in a most skillful manner by Mr. Martin, and it is now almost completely removed from the chalk in which it was embedded. Its delicacy and fragility may be suspected from its weight, scarcely thirty grammes, the mandible weighing about nine grammes more. The remarkable perfection and relative freedom from distortion render the specimen especially valuable for study. The mandible was displaced, in no wise obscuring other parts. The skull is of course depressed, but not so much as one might expect from the position in which it was lying, and there is a slight lateral compression to the right, but not enough to render the interpretation of the characters at all difficult. I give herewith a photographic reproduction of the back part of the skull, as it was seen before removal from the matrix. The anterior portion, on a separate block of matrix, has been omitted in order to show the hyoid bones lying partly beneath it. In the drawings I have attempted to restore the skull as nearly as possible to its living condition. There is yet a possibility that I have made the skull a little too broad, but, if so, the exaggeration must be so small as to be scarcely appreciable. The drawings were made by myself, at least insuring a careful study of the parts.

The premaxillary doubtless comprises the whole anterior portion of the beak, as in other known pterodactyls. In the middle behind, it separates the nares by a rather broad, gently convex

[1] *American Journal of Anatomy*, Vol. I, p. 297.

or laterally flattened bridge of stout bone, gradually and nearly uniformly decreasing in width posteriorly to an acute point between the frontals near the middle of the orbits. Its margins are rounded as far back as the union with the anterior processes of the frontals, which continue the same convex borders to the free margin of the orbits. The sutures separating the bone from the frontal posteriorly are indicated by lines exactly alike on the two sides, and hence evidently sutural. On the sides the union with the maxillæ is indeterminate. If this union is as in *Rhamphorhynchus*, as described by Woodward,[1] its position would be back of the anterior end of the nares. In *Scaphognathus*, however, Plieninger[2] would locate the suture at the anterior extremity of the nares. Its alveolar borders form straight, sharp, smooth ridges, with the inner wall two or three millimeters in width, meeting the palatal surface at an angle of about 135 degrees. The middle portion above is regularly rounded, forming an arc of about a third of a circle. This portion has its walls distinctly thicker than elsewhere, and has resisted compression; the sides from this median convexity seem to have been gently convex, meeting the middle convexity in a shallow groove. The surface is smooth, as in *Ornithostoma* (*Pteranodon*), without pits or depressions. As in that genus the texture of the bone of the beak has a distinct fibrillation longitudinally, sufficiently well marked to enable one to distinguish fragments from this part of the skeleton; a fact long since recognized by collectors of these animal remains in the field. I am convinced there were no pits, depressions, or conspicuous foramina on the premaxillary, and that neither in this genus nor in *Ornithostoma* was there a longitudinal ridge in the middle above. The proof of this is positive in both this genus and in *Ornithostoma*. On the under side, the bone forming the palatal surface, in part probably composed of the premaxilla, in part of the vomers, is of extreme tenuity, of the thickness of ordinary writing paper. It appears to have been gently concave through-

[1] *Ann. Mag. Nat. Hist.*, Vol. IX, No. 2, 1902.

[2] *Paleontographica*, Vol. XLI, p. 203, 1894.

out and smooth; on the sides between this bone and the roof the space was more or less filled in with a loose cancellated bone, but under the convexity of the middle there was a considerable cavity. On the under side of the premaxillary, back of the anterior ends of the nasals, are two pits or depressions, separated by a low ridge, evidently rhinencephalic fossæ.

The frontal bone is broad, unpaired, smooth, and nearly flat. Anteriorly it extends forward on either side as far as the posterior end of the nares, receiving between its two pointed processes the posterior pointed extremity of the premaxillary, as already described. There is no indication whatever of a median crest, a fact to which doubtless is due the position of the skull upon its dorsal surface, a position which I have never observed in specimens of *Ornithostoma*. Plieninger speaks of a rudimentary frontal crest in *Pterodactylus*, and its entire absence in this genus is remarkable. Posteriorly, the union with the parietal is indeterminable. On the sides it forms the horizontal, thin, superior border of the orbit for a little more than its posterior half, terminating in an angle a little before the beginning of the attachment of the postfrontal. At the anterior angle the border turns inward with a concavity looking forward, and then curves forward to be continuous with the sides of the premaxillary. The parietal, or fronto-parietal, continues the plane of the frontal in a long, U-shaped plane, forming the rounded posterior extremity of the skull. The sides of this slender U form the inner and front margin of the supratemporal fossa; from this slightly convex margin posteriorly the parietal descends downward and outward in a thin wing, articulating at the extremity with the posterior flattened end of the squamosal. This wing-like process narrows anteriorly to be continuous with the sides of the braincase.

The nasal is a slender bar of bone, beginning on the under side of the premaxillary, a little back of the middle of the nares, and extending downward and outward to unite with the ascending process of the maxilla to form the posterior boundary of the nares. Posteriorly it is a cribriform plate filling up the concave

sinus in front of the prefronto-lachrymal bone. The bone evidently continues over the outer surface of the maxillary process to unite with the lachrymal, and perhaps also with the ascending process of the malar. On the under side of the premaxillary the bones of the two sides may meet in the middle, though this seems doubtful.

The prefrontal and lachrymal cannot be distinguished from each other, and there seems to be some disagreement among writers as to which of the two elements should be called the prefrontal, were they distinguishable. The prefrontal must be that portion articulating along the sides of the premaxillary and frontal, while the lachrymal is that part which forms the anterior or anterior superior border of the orbit, either articulating directly with the frontal and the prefrontal, or with the prefrontal only, which one should expect. In the present specimen the compound element is sharply distinguishable from the frontal and premaxillary, as also the nasal. It begins on the side of the premaxilla a little back of the visible surface of the nasal, to which it is attached, as a slender pointed anterior process, and widens out posteriorly, forming a concave border, to which the thin, imperfectly ossified posterior part of the nasal attaches. Externally it widens out again into the broader horizontal plate forming the anterior superior roof of the orbit, which anteriorly curves downward to meet the jugal. Its orbital margin is thin.

The jugal bone extends forward on the outer and inferior side of the maxilla to beyond the middle of the nares. How far front it goes cannot be determined. In *Ornithostoma* the distinguishing suture, placed as in *Nyctodactylus*, seems to be continued as far forward as the anterior end of the nares, which would seem to indicate that the premaxilla does not reach as far back as in Rhamphorhynchus. At the front extremity of the orbit it sends up a slender process of bone, superimposed upon a thin expansion of the maxilla, to meet the lachrymal and nasal. Beyond this it forms a narrow bar, four or five millimeters in width, to the lower extremity of the quadrate, and then turns upward and backward a little more broadly to join, by a long

squamosal suture, the outer side of the quadrato-jugal, forming the anterior superior boundary of the lower temporal vacuity. In *Ornithostoma* it very clearly unites above with both the quadrato-jugal and postfrontal, and in all probability the same relations obtain in *Nyctodactylus*, but of this I am not sure.

The supratemporal bar is evidently formed of two bones, as in *Ornithostoma*. The superior one, joining the outer angle of the frontal (and parietal), is clearly the postfrontal or post-fronto-orbital. It extends backward to the head of the quadrate, also touching the squamosal, and probably also joining the jugal, as in *Ornithostoma*. The inferior outer part of the bar, uniting with the jugal, as described, anteriorly, the head of the quadrate, and apparently also the squamosal posteriorly, is, I suppose, the quadrato-jugal, though it corresponds precisely in position and relations with the bone I have called the pro-squamosal in the mosasaurs, following Baur. This bone in these and other lacertilians has, at various times, been called the pro-squamosal (Baur, Williston), the quadrato-jugal (Gegenbaur, Merriam, Baur), the squamosal (Owen, Huxley, Cope, Baur), and the supratemporal (Cope). In this pterodactyl the bone does not descend to separate the jugal from the quadrate. This, according to Seeley, is sometimes the condition among the pterodactyls. If so, the element must surely be the quadrato-jugal, and not the prosquamosal.

The squamosal seems clearly defined. It is a triangular, curved bone. A small process runs forward to join the post-frontal and "quadrato-jugal;" a broader and flat one curves downward and inward to join the wing-like squamosal process of the parietal, forming the parieto-squamosal arch, while a third joins the opisthotic (paroccipital), and probably also the head of the quadrate. It thus helps to form a small vacuity on the occipital region, between the opisthotic, parietal, and squamosal — the supraoccipital vacuity. It has nothing to do with the brain-case, as Seeley thinks it has in the European forms.[1]

The occipital condyle forms something less than a hemi-

[1] SEELEY, *Dragons of the Air*, London, 1901.

sphere, smoothly rounded, and with a small pit in its center. It seems to have looked downward and backward at an angle of about 45°, though it is possible that its angle with the horizontal plane of the skull may have been slightly greater. The basi-occipital forms a rounded, somewhat concave and roughened surface, clearly directed at a considerable angle backward. The paroccipital process is a broad, flattened bar, directed outward, backward, and somewhat upward to join the squamosal and quadrate broadly. Above them there is a small vacuity, as already described, while the outer extremity expands to join closely the inferior posterior surface of the quadrate, reaching nearly as far as their middle. The supraoccipital is directed upward and backward, joining the parietal in forming the posterior flattened prolongation of the skull. Their separation cannot be made out, but the two together form a considerable concavity looking downward and backward, with a slender median crest — the occipital crest — along the outer two-thirds.

The quadrate is more narrow above, and is firmly united with the opisthotic, squamosal, and "quadrato-jugal" above; below and to the outer side with the jugal; internally below with the pterygoid. The articular surface looks more nearly downward. The transverse axes of the two join each other at an angle of about 20°. Each has a deep oblique trochlear groove running from within outward and backward, with the stronger convexity at the inner extremity. The basi-sphenoid is an elongated, flattened, or slightly convex bone, somewhat wider in front than behind, with concave sides, and situated in the same plane with the pterygoids and palate. It joins the pterygoids at each anterior angle broadly and flatly.

The pterygoid is firmly and indistinguishably united with the quadrate at its lower inner extremity, close to the articular surface, by a broad process which ascends slightly to the plane of the palate. The two bones are separated from each other throughout their entire length, or at most touch each other by the slender tips of the anterior inner processes. Anteriorly the bone divides into two unequal processes — a slender one,

directed inwardly and anteriorly, closely approaching or touching its mate in the plane of the palate; and a larger one, which goes forward to beyond the middle of the narial vacuity, articulating with the ectopterygoid, and distally, by a long suture, with the palatine. Between the two there is an arrow-shaped vacuity posteriorly, bounded behind by the basi-sphenoid, the indentation for the head of the arrow formed by a small, thin inner process. This form of the pterygoid, it will be seen, is quite different from that figured and described by Woodward in Rhamphorhynchus. The slender inner process does not turn upward to meet a vomer, as Woodward thinks may be the case in the skull described by him, and the processes which, in his specimen, turn inward and upward are, in *Nyctodactylus*, closely applied to the inner side of the palatines. The pterygoid does not unite with the vomer in *Nyctodactylus*.

The ectopterygoids are thin, narrow bones, articulating broadly with the outer margin of the pterygoid, and exteriorly with the inner side of the slender posterior extremity of the maxilla. The bone is directed forward and outward, its concave margins forming the anterior and posterior borders of the pterygo-jugal and posterior palatine vacuities.

The palatines are long, narrow, thin bones, articulating by a long suture on the inner side with the pterygoid, and on the outer side with the maxilla. Anteriorly the union with the maxilla or vomers is indeterminable.

The relations of the maxilla can be made out only in its posterior part. Its union with the jugal has already been indicated. Posteriorly it sends up a thin, curved process to meet the nasal, forming the posterior inferior boundary of the nares. Back of the thickened portion of this process there is a thin plate reaching back under the superior process of the jugal, the bottom of an oval depression or excavation, which clearly corresponds to the antorbital vacuity of the earlier pterodactyls. From this it is evident that the antorbital vacuity is not united with the nares in either this genus or *Ornithostoma*.

The vomer cannot be made out. If it forms a part of the

palatal surface, it is so indissolubly united with the maxillæ, palatines, and premaxillary that no signs of its union can be detected. One thing is certain, it does not separate the narial vacuities, and in all probability it does not touch the pterygoid at all.

Mandibles.—The mandibles are preserved nearly complete, their tip only being wanting—the portion which led to the detection of the specimen as it protruded from the chalk. It was lying horizontally, with the under surface uppermost, but has been entirely removed from the matrix. It has suffered a slight lateral compression to the left.

The cotylar cavity fits well on the condyles of the quadrate. The projection back of the articulation is very slight, less so than in *Ornithostoma*. The rami are slender, flattened from within outward, and are broadest at about their middle, the upper thin margin being gently convex from near the cotylus to as far forward as the symphysis, which begins about fifty millimeters in advance of the anterior end of the external nares. From the beginning of this symphysis, diminishing in width to the anterior extremity, the under margin is convex, not carinated. About twenty-five millimeters back of the true symphysis of the dentaries there is a symphysis of the thin bone which forms the floor of the mouth. This forms a thin, deeply curved hind border joining rami about midway between their upper and lower margins. The floor of the mouth from here onward seems to have been, like the opposing palatine surface, smooth, and nearly plane. The space between these surfaces, was, however, somewhat greater posteriorly than anteriorly, since the alveolar parapet is considerably deeper posteriorly. The concave posterior margin of the floor is about twenty millimeters in front of the anterior end of the internal narial vacuity. Anteriorly the margins of the mandibles are as in the upper jaws. In cross-section through the symphysis the mandible was, I think, somewhat concave or partly plane on the sides, with the under margin convex, not convex throughout, as I have thought might be the case in *Ornithostoma*. The mandible certainly could not have possessed very great strength in seizing.

Openings.—The external nares are large and ovate, looking outward and upward and forward. They are bounded above by the premaxillary anteriorly, the nasal posteriorly, below by the maxilla (and premaxillary anteriorly?), behind by the nasal above and the maxilla below.

The orbits are longer than wide, looking outward and but slightly upward and forward. The superior emargination above (doubtless roofed over in life by the integument) if not taken into account would leave the orbit oval in shape, with the anterior end rather broader than the posterior. It was bounded above by the frontal, prefrontal, and lachrymal, by the lachrymal and malar in front, the malar below and behind, and the postfrontal in part behind. It had a ring of thin, large sclerotic plates, which were preserved in displaced positions. The separate plates were not united by imbrication, as in the mosasaurs.

The supratemporal vacuity is broadly oval in shape, deep anteriorly and shallow posteriorly, bounded on the inner side by the parietal, on the outer side by the postfrontal and squamosal, and behind by the margin of the squamosal and parietal process. It opens anteriorly into the spheno-quadrate vacuity, and has a narrow slit between the squamosal and opisthotic. The infratemporal vacuity is long and narrow, broader posteriorly. It is bounded on the inner side and behind by the quadrate, externally and above by the jugal and the quadrato-jugal. The large oval vacuity between the quadrate and the basi-sphenoid is broadest at the middle, bounded in front by the quadrate process of the pterygoid, behind by the paroccepital process. The pterygo-jugal vacuity is irregular and elongated, bounded behind by the articular end of the quadrate, on the outer side by the jugal and maxilla, on the inner side by the pterygoid posteriorly and the ectopterygoid anteriorly. The posterior palatine vacuity is a small oval vacuity placed obliquely between the ectopterygoid behind, and the palatine in front, barely touching, if at all, at the extremities the pterygoid and the maxilla. The interpterygoid vacuity is arrow-shaped, placed between the basi-sphenoid posteriorly and the pterygoids on the sides. The narial vacuity

is a very large opening, oval in general shape, but with a triangular projection behind made by the two inner processes of the pterygoids, and a smaller triangular process in front extending back from the roof of the mouth. It was not divided in the middle and was doubtless covered over for the most part by membrane pierced by the internal nares.

The skull of *Nyctodactylus*, while presenting very great resemblances to that of *Ornithostoma* (*Pteranodon*) differs in important characters. Its quadrate is much shorter, terminating below in the condyle for the mandible nearly below the middle of the orbit, while in *Ornithostoma* the articulation is in advance of the orbit. The orbit and supratemporal vacuities are proportionally larger, and there is no crest, not even a rudimentary one. The bar between the orbit and the nares is narrower, the frontal bone less broad relatively in *Ornithostoma*.

In *Nyctodactylus* we have a less highly specialized type of pterodactyl than is seen in *Ornithostoma* as is evidenced by the absence of the crest, the plane frontal bone, and the less oblique position of the quadrate. On the other hand the genus has the same type of skull, and toothless jaws, and the general proportions of the skeleton throughout are the same. I believe that the resemblances between the two genera are of much greater importance than the differenees. These differences rest in the non-articulation of the scapula with the supraneural plate of the vertebræ, in the absence of crest, and the position of the quadrate especially. Both forms are toothless. If much importance is given to the scapular articulation the two genera must go into different families at least — *Ornithostoma* among the Ornithocheiridæ, and *Nyctodactylus* with the Pterodactylidæ. But such a severance is, I, believe, questionable. It is a rather curious instance of parallel growth that has brought about the toothless forms of *Ornithostoma* from the toothed *Ornithocheirus*, and the toothless *Nyctodactylus* from the toothed *Pterodactylus*; possibly this has been the phylogeny. On the other hand, it would also seem possible that the same toothless form has been ancestral to both

Nyctodactylus, the lesser, and *Ornithostoma*, the more, specialized type.

If my interpretation of the elements of the skull of *Nyctodactylus* is correct, I fail to see any marked avian resemblances in it. The only character that might be considered as such is the undivided narial vacuity, aside from the lightness of the bones and their closely united sutures, both adaptive characters. The supratemporal arch is purely reptilian, as is the presence of the ectopterygoid, etc. The union of the premaxillary with the frontal is found in the plesiosaurs. A further discussion of this question I hope to present in a future paper, in which I shall give a more detailed description of the remainder of the skeleton, with illustrations.

I am convinced that the arrangement of the ribs back of the sternum, not only in *Nyctodactylus*, but in other pterodactyls, is different from what has been generally supposed and figured. They extended outward in the plane of the wing membrane, which they served in a measure to support, and did not enclose the ventral cavity. From a recent examination of the type of *Rhamphorrhynchus phyllurus* Marsh, I am satisfied that this was their function in that animal, and I doubt not it was also in all other pterodactyls. This difference in function accounts satisfactorily for the marked contrast in slenderness between the anterior and posterior ribs, as also for the slight curvature of the latter.

The hyoid bones of the present specimen are quite like those of other pterodactyls — long, slender rods. They are shown in part in Plate I. At the back of the skull in the same plate is also seen a small triangular or V-shaped bone, which I take to be the proatlas.

It will be of interest to note that in the matrix underlying the skull occurred several specimens of the Cirriped *Stramentum*, together with a vivid impression of a Lepas-like barnacle having a slender, flexible, naked peduncle about 40 mm in length. The capitulum seems to have been enclosed either in chitinous or membranous plates, evidences of which are present, and impres-

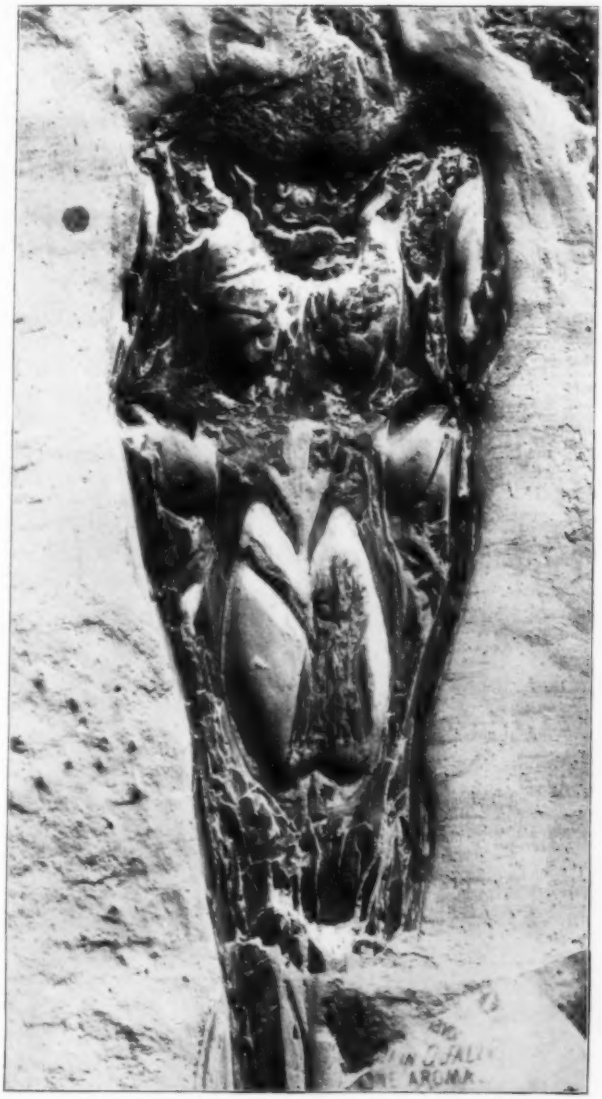

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Fig. 1.

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Fig. 2.

sions of the cirri are plainly present. Other impressions of phyllopods or ostracods are also abundant in the matrix.

S. W. WILLISTON.

UNIVERSITY OF KANSAS,
Lawrence, April, 1902.

EXPLANATION OF PLATES.

PLATE I. Under surface of posterior part of skull, lying in the matrix slightly enlarged. Near the anterior end are seen the two hyoid bones, and in the occipital region, the small, triangular proatlas.

PLATE II. Fig. 1, Under view of skull; Fig. 2, upper view of same, both a little more than half natural size; *bo*, basi-occipital; *ep*, ectopterygoid; *fr*, frontal; *ipv*, interpterygoid vacuity; *itv*, infratemporal vacuity; *j*, jugal; *l*, lachrymal; *mx*, maxilla; *na*, nares; *nas*, nasal; *oc*, occipital condyle; *pa*, parietal; *pal*, palatine; *pf*, prefrontal; *pof*, postfrontal; *ppv*, posterior palatine vacuity; *px*, premaxillary; *q*, quadrate; *qj*, quadrato-jugal; *sq*, squamosal; *z*, pterygo-jugal vacuity.

CROTALOCRINUS CORA (HALL).

AMONG the internal casts of crinoids which occur commonly in the dolomitic Niagaran limestone of northeastern Illinois and southeastern Wisconsin, is a species which was first described by Hall in 1868 under the name *Cyathocrinus cora*. The cotypes of this species, two in number, are recorded from Racine, Wis., and are now preserved in the collections of the American Museum of Natural History in New York. Specimens very much larger than these types frequently occur in the dolomite near Chicago, but they resemble them in all essential characters and all are undoubtedly specifically identical.

The body of this crinoid is more or less subglobular in form, with a large column, and has been but rarely found preserved in any condition other than as internal casts. The plates composing the body are arranged essentially as in members of the genus Cyathocrinus. There are five large underbasals which support five large basals, four of which are hexagonal in outline, the fifth being heptagonal by reason of the truncation of the distal angle for the support of a single subquadrangular anal plate. The radials are large, wider than high, and are in contact laterally, except the two posterior ones, which are separated by the large anal plate. Until the discovery of the specimen illustrated in the present paper, the plates above the radials have never been observed, or at least they have never been recognized as belonging to this species.

In 1900 a single imperfect radial plate of a crinoid, with brachial plates attached, was recognized by Weller as representing the genus Crotalocrinus, and was described under the name *C. americanus*. This specimen is a natural mold of the exterior, and was found associated with *Cyathocrinus cora*, but there was no evidence by which the two forms could be correlated.

There has recently come into the possession of the Walker

Museum, through the generosity of Mr. G. F. Harris, of Chicago, a specimen of the so-called *Cyathocrinus cora*, upon which nearly all of the plates of the calyx are preserved, as well as some of the brachial plates. This specimen demonstrates that the type of *Crotalocrinus americanus* is nothing more than a radial plate with brachials attached of the so-called *Cyathocrinus cora*, and that the latter species must be transferred from the genus Cyathocrinus into Crotalocrinus. This remarkable genus of crinoids, therefore, which has hitherto been considered as such a rarity in the Niagaran fauna of America, proves to be one of the common members of the fauna of this age in Illinois and Wisconsin. It is of especial interest because it is one of those peculiar forms which relates the Niagaran faunas of the interior of North America, so closely with the faunas of Gotland and England.

This American species of Crotalocrinus is most closely allied to *C. rugosus* Miller, *var.*, from Gotland, as illustrated by Angelin.[1] Both have the same subglobular form of calyx, constricted at the top of the radial plates, and both have the same style of surface markings, consisting of shallow furrows which cross the sutures dividing the plates at right angles. In the American specimens these markings are so pronounced as to be usually discernable even on internal casts. The arrangement of the fixed brachial plates in the two species, however, is quite different, if Angelin's illustrations can be depended upon.

In the arm plates of Crotalocrinus the axial canals are a conspicuous feature. In converging toward the base of the arm, these canals unite into a single trunk which pierces the radial plate. The axial canals are well shown in both the specimens preserving the brachial plates, and the casts of the canals are frequently more or less well preserved in the internal casts of the species as it is ordinarily preserved.

The species which has been described as *Cyathocrinus vanhornei* S. A. M. is probably another member of the genus Crotalocrinus. It is known only from internal casts, but these speci-

[1] *Iconog. Crin.*, Plate 17, Figs. 8, 8a.

mens usually preserve the cast of the basal portion of the axial canal where it enters the radial plate. The species differs from *C. cora*, especially in the strong constriction of the calyx at its middle line.

In the light of the observations here recorded, the synonomy of *Crotalocrinus cora* will stand as follows:

Crotalocrinus cora (Hall).

1868. *Cyathocrinus cora* Hall, *Twentieth Rep. N. Y. State Cab. Nat. Hist.*, p. 324, Pl. XI, Figs. 13, 14.

1870. *Cyathocrinus cora* Hall *Twentieth Rep. N. Y. State Cab. Nat. Hist.* (Rev. Ed.), p. 366, Pl. XI, Figs. 13, 14.

1879. *Cyathocrinus cora* W. & S., *Rev. Palæocr.*, Pt. I, p. 85.

1881. *Cyathocrinus cora* S. A. M., *Jour. Cinn. Soc. Nat. Hist.*, Vol. IV, p. 171.

1900. *Cyathocrinus cora* Weller, *Bull. No. 4 Nat. Hist. Surv., Chicago Acad. Sci.*, p. 62, Pl. XIV, Figs. 6–10.

1900. *Crotalocrinus americanus* Weller, *Bull. No. 4, Nat. Hist. Surv., Chicago Acad. Sci.*, p. 143, Pl. XIV, Fig. 1.

EXPLANATION OF PLATE.

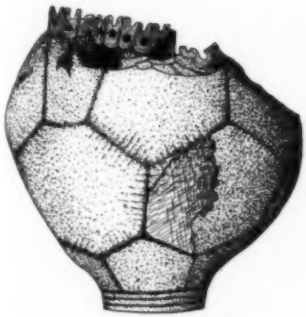
FIG. 1.—A nearly perfect specimen of the calyx of *Crotalocrinus cora* showing the plates of the calyx with some of the brachial plates.

FIG. 2.—An internal cast of *Crotalocrinus cora*, showing the broken bases of the casts of the axial canals where they pierce the radial plates.

FIG. 3.—An outline of the specimen which was made the type of *Crotalocrinus americanus*, showing the arrangement of the fixed brachial plates in *Crotalocrinus cora*.

FIGS. 4–5.—The casts of two radial plates of *Crotalocrinus cora*, preserving the internal casts of the axial canals.

STUART WELLER.



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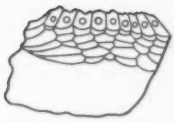

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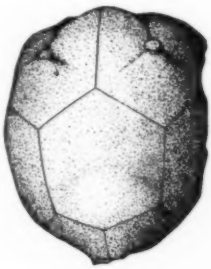

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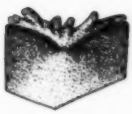

5

THE CARBONIFEROUS FISH-FAUNA OF MAZON CREEK, ILLINOIS.

Of the thousands of fossiliferous ironstone nodules of Coal Measure age, occurring at Mazon Creek, near Morris, in Grundy county, Illinois, only a small percentage afford indications of vertebrate remains, and these consist principally of detached fish-scales. Occasionally, however, complete individuals of fossil fishes, and still more rarely, amphibian skeletons have been brought to light, but all told the number of even tolerably perfect specimens preserved in different museums is very insignificant. Probably the two finest series of Mazon Creek nodules ever brought together are the Lacoe collection, belonging to the United States National Museum in Washington, and the Strong collection, purchased by the late Professor Marsh for the Peabody Museum, at Yale College. Shortly before the decease of Professor Marsh, nearly all of the fossil fishes in the Strong collection were placed by that gentleman in the hands of the writer for study and description; and more recently some further material has been loaned for the same purpose by Professor C. E. Beecher, to whom grateful acknowledgments are due.

Mazon Creek fish-scales have been exhaustively studied by E. D. Cope[1] and O. P. Hay,[2] and the latter has also described a nearly perfect example of a Palæoniscid fish, named by him *Elonichthys hypsilepis*. A few other Palæoniscids and Platysomids have been described by Cope[3] and by Newberry and Worthen;[4] and two Acanthodian species have recently been made known by the present writer.[5] These citations complete the literature references on Mazon Creek fishes. In the following paragraphs

[1] *Proc. Amer. Phil. Soc.*, Vol. XXXVI (1897), pp. 71–82.

[2] *Ibid.*, Vol. XXXIX (1900), pp. 96–120.

[3] *Proc. U. S. Nat. Museum*, Vol. XIV (1891), p. 462.

[4] *Pal. Illinois*, Vol. II (1866), and Vol. IV (1870).

[5] *Bull. Mus. Comp. Zool.*, Vol. XXXIX (1902), pp. 93, 94.

brief descriptions are given of two species of *Acanthodes*, and one each of *Cœlacanthus* and *Elonichthys*, with a list of the known vertebrate fauna occurring at this locality.

GENUS ACANTHODES, AGASSIZ.

Representatives of the Acanthodii are extremely rare in the Palæozoic rocks of North America. If we neglect the detached spines of *Machæracanthus*, and the indeterminable mass of scales described by J. M. Clarke as *Acanthodes pristis*,[1] American Acanthodians are limited to but three species of *Acanthodes* and one of *Mesacanthus*.

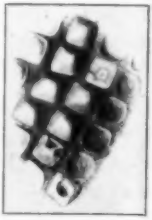

FIG. 1*a*.—Shagreen granules of *A. marshi*. × 4.

Of these *Acanthodesconcinnus* Whiteaves and *Mesacanthus affinis* (Whiteaves) occur in the Upper Devonian of Scaumenac Bay, Canada, and the recently described *Acanthodes marshi* and *A beecheri* are from the Mazon Creek locality, in Illinois.

FIG. 1.—*Acanthodes marshi* Eastm. Coal-measures, Mazon Creek, Ill. Pectoral fin with associated actiontrichia and fin-spine. × 4.

Acanthodes marshi Eastman.

This species is remarkable for being one of the largest, as, on the other hand, *A. beecheri* is one of the smallest known *Acanthodians*. In *A. marshi*, not only are the shagreen granules much coarser than those of *A. bronni* and *A. wardi*, which are the largest of European species, but the fin-spines are considerably longer and stouter, averaging about 9^{cm} long, and from .5 to .8^{cm}

[1] *Bull. U. S. Geol. Surv.*, No. 16 (1885), p. 42.

wide. In Fig. 1 is shown a very interesting pectoral fin preserved in counterpart, and retaining the actinotrichia in natural association with the spine. The fibrous rays are quite long and numerous as compared with those of other species, and extend well up toward the point of insertion of the spine. There is no trace here, unfortunately, of a basal cartilage abutting against the proximal end of the spine, nor does this specimen display any of the dermal granules with which the fin-membrane was stiffened, although such are exhibited by a smaller specimen belonging to the Yale Museum. The scales of *A. marshi* are in

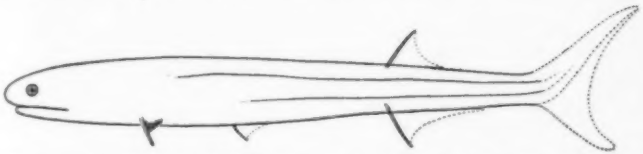

FIG. 2.—*Acanthodes beecheri* Eastm. Coal-measures, Mazon Creek, Ill. Restoration showing outline of body and position of fins. $\times\frac{2}{1}$.

the form of shagreen granules, averaging about one square millimeter in size, smooth and polished externally, and gently convex or rounded on both the outer and attached surfaces. (Fig. 1*a*). The internal structure consists of fine layers of dentine arranged in quadrate fashion about a small central pulp-cavity. The best account of the microscopic structure of Acanthodian and Thelodus-like scales is that given by Rohon about nine years ago.[1]

Acanthodes beecheri Eastman.

Description. — A very small species, attaining an extreme length of about 5.5 cm. Body elongated and slender, the maximum depth being contained about nine times in the total length. Pectoral spines not much stouter or longer than the others; pelvic fins small, slightly nearer the pectorals than the anal; anal fin slightly larger than the dorsal, which is placed immediately behind. Length of dorsal and anal spines greater than maximum depth of trunk. Caudal lobe remarkably elongate. Scales extremely minute.

This species is represented by two nearly complete individuals preserved in counterpart and belonging to the Yale Museum,

[1] *Mem. Acad. Imp. Sci. St. Petersbram*, Vol. XLI (1893), No. 5, p. 22.

neither of which, however, exhibits the caudal region satisfactorily, nor are the heads well preserved. Only the dorsal and anal fin-spines are displayed by the larger specimen; but in the smaller all the fin-spines are preserved, although the dorsal is slightly displaced and the distal ends of the pectorals are wanting. The accompanying figure, based on both specimens, is of composite nature, and represents the general outline and proportions of the fins, the restored parts being indicated in dotted lines.

FIG.—3. *Cœlacanthus exiguus*, sp. nov. Coal-measures, Mazon Creek, Ill. Complete individual, lacking posterior dorsal and anal fins. ×$\frac{3}{4}$.

GENUS CŒLACANTHUS, AGASSIZ.

J. S. Newberry records having received from Mazon Creek "a single specimen each of *Eurylepis* and *Cœlacanthus*, probably not distinct from those found at Linton, Ohio." No examples of the former genus have come under the writer's observation, but ornamented scales and head-plates referable to *Cœlacanthus* sometimes occur in Mazon Creek nodules, and very rarely there are found complete fishes of small size, evidently quite distinct from other described species. In most specimens the posterior dorsal, anal, and pectoral fins are lacking, and it seemed at first sight as if the second dorsal had become lost through specialization. One individual, however, shows it very distinctly, and the absence of this and the anal in the remaining examples is to be attributed to faulty preservation.

Cœlacanthus exiguus, sp. nov.

Description.—A small species, attaining a maximum length of about 4.5^{cm}. Trunk narrow and elongated, the head occupying about one-fourth of the total length. First dorsal consisting of relatively few stout rays, and situated slightly in advance of the pelvic pair; second dorsal midway between the first dorsal and principal caudal; the latter comprising nine stout rays above and below. [Scale-structure and ornamentation of head-bones not observed.]

This species is represented by ten specimens in the Yale, and one in the Harvard Museum, most of them being only about 3^{cm} long, and very deficient in preservation. They agree in having a narrow, gradually tapering body, which terminates in an equilobate caudal fin, with indications that the axis was prolonged into a supplementary caudal. The first dorsal and caudal, owing to their stronger attachment, are present in nearly all specimens, but the remaining fins have in most cases become destroyed. The first dorsal has usually seven or eight stout rays, and is situated near the middle of the trunk. Ten long, hollow rays are to be counted in the single specimen displaying the posterior dorsal, and nine above and below in the symmetrical caudal. The neural and hæmal spines are very long in the abdominal and caudal regions. The ossifications of the axial skeleton are continued nearly to the termination of the principal caudal. The squamation must have been exceedingly delicate, as no indications of scales are to be observed in any of the specimens, nor do any of them have the cranial elements satisfactorily preserved.

FIG. 4.—*Elonichthys perpennatus*, sp. nov. Coal-measures, Mazon Creek, Ill. Complete individual, the distal portions of median fins not fully shown. ×1.

GENUS ELONICHTHYS, GIEBEL.

Two closely related species are already known from Mazon Creek, *E. peltigerus* Newberry, and *E. hypsilepis* Hay. A study of the type-specimen of Newberry and Worthen's so-called "*Amblypterus macropterus*," now preserved in the Yale museum, leaves no doubt that this is only a mutilated individual of *E. peltigerus*. The type of the following new species is preserved in the Museum of Comparative Zoölogy.

Elonichthys perpennatus, sp. nov.

Description.—A very small species, having a total length of about 2.5^{cm}, of which the head occupies a little less than one-fourth. Fins extremely well

developed, the pectorals unusually long, and anal much extended; fulcra minute. Scales relatively small, obliquely striated; dorsal ridge-scales enlarged.

Only one individual is at present known of this interesting little form, which is shown in Fig. 4. The head is poorly preserved, and the distal extremities of nearly all the fins are either broken away or obscured by matrix. Nevertheless, sufficient characters remain for the recognition of this as a distinct species of *Elonichthys*, its chief peculiarity consisting in the remarkable development of all the fins. The pectorals are fully one-fourth the total length, and the anal has a more extended base-line than in any other species of the genus. The dorsal appears to have been high and acuminate, but is largely concealed by matrix. The caudal is also unfavorably exposed, and flexed out parallel with the main axis; but it is plain that the upper lobe was much prolonged, and covered with very large, striated ridge-scales. The dorsal-fin rays appear to have been widely jointed; the articulations of the other fins are not clearly recognizable. The dermal rays of the anal and lower lobe of the caudal are directly supported by the large hæmal spines, which are firmly united with their arches. The squamation is nowhere well preserved, but is best indicated in the anterior part of the trunk. The cranial structure does not admit of particular description. Appearances suggest that the specimen here described is an immature individual, differing however, from other known species.

LIST OF CARBONIFEROUS VERTEBRATES OCCURRING AT MAZON CREEK, ILLINOIS.

ELASMOBRANCHII.

1. *Pleuracanthus* (*Diplodus*) *compressus* Newb. (Occurs also in Ohio and Indiana.)
2. *Pleuracanthus* (*Diplodus*) *latus* Newb. (Occurs also in Ohio and Indiana.)
3. *Pleuracanthus* (*Diplodus*) *lucasi* Hay.
4. *Acanthodes beecheri* Eastm.
5. *Acanthodes marshi* Eastm.
6. *Campodus scitulus* (St. J. and W.).

DIPNOI.

7. *Ctenodus* sp. indes.
8. *Sagenodus foliatus* Cope.[1]
9. *Sagenodus lacovianus* Cope.[1]
10. *Sagenodus occidentalis* (Newb. and W.).[1] (Occurs also at Linton, Ohio.)
11. *Sagenodus quadratus* (Newb.).[1] (Occurs also at Linton, Ohio.)
12. *Sagenodus quincunciatus* Cope.[1]
13. *Sagenodus reticulatus* (Newb. and W.).[1]
14. *Sagenodus textilis* Hay.[1]

[1] Founded on scales.

CROSSOPTERYGII.

15. *Rhizodopsis* (?) *mazonius* Hay.[1]
16. *Cœlacanthus exiguus* nobis.
17. *Cœlacanthus robustus* Newb.[1] (Occurs also at Linton, Ohio.)

ACTINOPTERYGII.

18. *Eurylepis* sp. indet. (*fide* J. S. Newberry).
19. *Rhadinichthys gracilis* (Newb. and W.).
20. *Elonichthys hypsilepis* Hay.
21. *Elonichthys peltigerus* Newb.[2] (Occurs also at Linton, Ohio.)
22. *Elonichthys perpennatus* nobis.
23. *Platysomus circularis* Newb. and W.
24. *Platysomus lacovianus* Cope.
25. *Platysomus orbicularis* Newb. and W.

AMPHIBIA.

26. *Amphibamus grandiceps* Cope.

[1] Founded on scales.

[2] Including the so-called "*Amblypterus macropterus*" Newb. and Worthen.

C. R. EASTMAN.

Reviews.

SUMMARIES OF THE LITERATURE OF STRUCTURAL MATERIALS. II.

EDWIN C. ECKEL.

BERKEY, C. P. *Origin and Distribution of Minnesota Clays.* Amer. Geologist, Vol. XXIX, pp. 171–177, March, 1902.

Residual clays, derived either from feldspathic rocks or from limestones, are of slight importance in Minnesota. The larger clay working establishments of the state are using shales, stream deposits, or glacial lake clays; the smaller brick plants of local importance use till or loess.

The shales of most importance are those of the Ordovician and Cretaceous. The Ordovician shales are found only in the southeastern portion of the state. Most beds are too calcareous for use, but one company in Minneapolis utilizes Ordovician shales in the manufacture of an exceptionally fine line of front and pressed brick. The Cretaceous shales are used in the manufacture of stoneware at Red Wing.

The clays may be divided as to origin into glacial till, glacial lake clays, glacial stream deposits, recent alluvial deposits, and wind deposits.

Locally the till includes clay deposits of workable size. These clays differ in character according to the drift in which they are inclosed. The "gray drift" which has been brought by ice movements from the north and northwest carried fine-grained, calcareous, light-burning clays, though in places weathering may have removed enough lime to give red-burning clays. The "red drift" brought in from the north and northwest carries coarser grained clays with an excess of iron, which consequently burn red.

Glacial lake clays, laid down in quiet water in interglacial periods, are confined to the eastern border of the state, where extensive deposits occur and are worked on a large scale.

Glacial stream deposits include the river silts deposited during the withdrawal of the ice. Clays of this type are worked on the Mississippi river between Minneapolis and Little Falls, and on the Missouri river between Shakopee and New Ulm. These clays are obtained from the terraces bordering the present river channels, and burn cream or gray. They are the most important of the Minnesota clays, large plants using them being located at Chaska and Minneapolis.

Recent alluvial deposits occur in the same areas as the last class and in many cases cannot be differentiated from them.

Most of the smaller brick plants of the state work on material obtained from loess deposits. The clayey loams of this class are widely distributed, but are nowhere of great thickness or value.

BLATCHLEY, W. S., AND ASHLEY, G. H. *The Lakes of Northern Indiana and their Associated Marl Deposits.* Twenty-fifth Ann. Rept. Indiana Dept. Geology and Natural Resources. Pp. 31–321, Pls. 1 and 6–12, Figs. 1–70, 1901.

The origin and uses of marl are first discussed, issue being taken with C. A. Davis on some points connected with the importance of Characae in the formation of marl deposits. The marl deposits of the state are then discussed separately in great detail.

Marl deposits of sufficient size to justify the erection of cement plants occur in Indiana only in the three northern tiers of counties. Areally, the largest of these deposits is in Lake Wawasee, which contains about 1,700 acres, while the maximum thickness (45 feet) is reported from Turkey Lake, Lagrange co. A deposit of marl equal to one covering 160 acres, ten feet thick, will supply for thirty years a plant with a capacity of 500 barrels per day. Deposits of such size are termed "workable deposits" in the present report. Thirty-two such deposits were found and are described and mapped in detail. A number of other deposits are described which, though of sufficient size, have the larger part of their area covered by ten feet or more of water and are therefore not at present workable. Improved appliances for raising marl from beneath such depths of water would render these deposits available.

BLATCHLEY, W. S. *Portland Cement.* Twenty-fifth Ann. Rept. Indiana Dept. Geology and Natural Resources. Pp. 1–30, Pls. 2–5, 1901.

A summary of the history, uses, composition, manufacture, and testing of Portland cement is followed by a brief history of the industry in Indiana.

Portland cement was first manufactured in Indiana at South Bend in 1877, from marl and clay burned in dome kilns. Operated with varying fortune, this plant was shut down finally in 1898. Two plants, also using marl and clay, but burning the mixture in rotary kilns, commenced operations in 1900, and at the time of report three additional plants were in prospect.

CUMMINGS, URIAH. [*Production of*] *American Rock Cement* [*in the U. S. during 1899*]. Twenty-first Ann. Rept. U. S. Geol. Surv., Pt. VI continued, pp. 407–411, 1901.

Résumé of the condition of the American natural cement industry during 1899, with statistics of production. Analyses and tests are quoted of a Portland cement manufactured at Chattanooga, Tenn., by burning a natural rock without admixture.

ECKEL, E. C. *The Portland Cement Industry in New York.* Engineering News, Vol. XLV, pp. 365–367, 1901.

Résumé of early history of Portland cement manufacture in New York, with descriptions of the six plants operating in 1900, and notes on the technology.

Until recently most New York plants used a mixture of marl and clay, burned in dome kilns. At present, however, the use of rotary kilns, operating on mixtures of hard limestone and clay, is increasing rapidly, half the plants in operation in 1900 being of this type.

Slag Cement Manufacture in Alabama. Eng. News, Vol. XLVII, pp. 1–62, 1902.

Description of two slag cement plants operating in Alabama, with notes on technology of slag cement in general.

The Classification of the Crystalline Cements. Amer. Geologist, Vol. XXIX, pp. 146–154, March, 1902. Reprinted in Cement, Vol. III, pp. 109–114, May, 1902. Reprinted in part in Engineering News, Vol. XLVI, p. 354, May 1, 1902.

A classification of cementing materials, with notes on raw materials, technology, and the properties of the various products. The grouping offered is as follows:

I. *Simple cements;* including those materials which are produced by the expulsion of a liquid or gas from the raw material; and whose set is due to the simple reabsorption of the same liquid or gas and a reassumption of original composition.

I*a*. *Hydrate cements;* set due to reabsorption of water. Plaster-of-Paris, cement plasters, Keene's cement, Parian cement, etc.

I*b*. *Carbonate cements;* set due to reabsorption of carbon dioxide. Limes, magnesian limes, etc.

II. *Complex cements;* including those cementing materials whose set is due to the formation of new compounds during manufacture or use.

II*a*. *Silicate cements;* set due to the formation of silicates. Hydraulic limes, natural cements, Portland cement, pozzuolanic cements.

II*b*. *Oxychloride cements;* set due to the formation of oxychlorides. Sorel stone, etc.

FREAR, WILLIAM, *The Use of Lime upon Pennsylvania Soils.* Bulletin 61, Pa. Dept. Agriculture. 170 pp., 1900.

Principally a discussion of lime in its relation to agriculture, but contains also very satisfactory accounts of limestones (in general) and lime-burning, with 273 analyses of Pennsylvania limestones, mostly compiled from reports of the Second Geological Survey of that state.

HARRIS, G. D., and VEATCH, A. C. *General Geology (of Louisiana).* Geological Survey of Louisiana, Report for 1899. Pp. 55–138, Pls. 1–11, Figs. 2–5, geological maps.

Report on the stratigraphic and economic geology of the state. The matter of clays, limestones, sandstones, and gravels (pp. 127–132) is here summarized.

Good brick clays are common in the alluvium and yellow loam, and are also found at several places in the hill-lands. The Eocene clays commonly lack plasticity, though some beds occur which will make a fair quality of earthenware. Good potter's clay occurs in the Lignitic, near Robeline, where it has been utilized. The clays of the Grand Gulf hills seem to be more promising than any others in the state, good exposures occurring in Catahoula and Vernon parishes.

The sandstones of the state are of two classes; the ferruginous sandstones of the Eocene and Lafayette, and the siliceous sandstones of the Grand Gulf. The former are widely distributed, but are unimportant as structural materials. The siliceous Grand Gulf sandstones are of greater value, and have been used for jetty work and railroad ballast.

Limestones of Cretaceous age outcrop at Winnfield, Coochie Brake, and Bayou Chicot. The first is a pure limestone, which may be used for lime, but not for building stone. The other two are of greater value for structural purposes. Limestone concretions occurring in the Tertiary are of local importance for lime or road metal.

The gravels of the Lafayette are rather extensively used as road metal and railroad ballast.

HILLEBRAND, W. F. *Some Principles and Methods of Rock Analysis.* Bull. 176, U. S. Geol. Surv. 8vo. Pp. 115, Figs. 15, 1900.

Detailed discussion of the methods to be followed in analyses of the silicate rocks. Stress is laid on the importance of complete and thorough analyses, and the chemist is warned against neglect to determine elements (such as strontium, barium, vanadium, etc.), often disregarded as unimportant.

HOPKINS, T. C. *Clays and Clay Industries of Pennsylvania.* III, *Clays of the Great Valley and South Mountain Areas.* Appendix to the Ann. Rept. Pa. State College for 1889–1900. 8vo, pp. 45, 1900.

Over half the paper is taken up with a discussion of the white clays of the Great Valley; the remainder containing short chapters on respectively the red brick, paving brick, and tile industries; with a brief account of the economic products, other than clays, of southeastern Pennsylvania.

The most valuable clay deposits in southeastern Pennsylvania are those occurring in the Cambro-Silurian areas of the Great Valley and South Mountains. These clays are typically white; commonly bluish-white to gray on fresh exposures, but soon weathering pure white. Closely associated with the white clays are others stained more or less by iron oxide, and being therefore yellow to brown in color. The white clays are invariably high in silica, and low in alumina. Their iron content is also low, but the alkalies are always too high to give refractory material. Genetically, the white clays are direct decomposition products of light-colored hydromica slates which occur interbedded with other Cambro-Ordivician rocks. In certain openings the clays are shown grading into the undecomposed slates. They were originally intercalated beds in a series of quartzites, limestones, etc.; but on the weathering of the rocks the clay derived from the disintegrated slates crept down hillsides, filled cavities in the other rocks, etc.—so that now the deposits are somewhat irregular, lenticular masses of varying extent. At present the clays are largely used in the manufacture of paper, and to a less extent for white tiles, and white and enameled brick.

Red building brick is made, in the Great Valley, from residual limestone clays, residual shale clays, and alluvial deposits. Of these classes the first is the most important. The clays residual from limestone make good brick, though often carrying numerous fragments of limestone, quartz, etc.

Vitrified brick is manufactured at six plants. Three of these use Triassic shale; one, Hudson River shale; while the remaining two use shales from the Cambro-Ordovician series.

Ornamental brick and tile are manufactured at several plants, various materials being in use, including clays, slates, etc.

IHLSENG, MAGNUS C. *The Road-Making Materials of Pennsylvania.* Bulletin 69, Pa. Dept. Agriculture. Pp. 104, Figs. 1–17, relief map, colored geologic map, 1900.

General discussion of road materials, their qualities, and testing; influence of topography on road construction; methods of constructing and repairing roads, etc.

Scattered notes on various Pennsylvania road materials, with a section on the distribution, by counties, of such materials.

LEWIS, F. H. *Hydraulic Cement Industry in the United States in 1899.* Mineral Industry, Vol. VIII, pp. 84, 85, 1900.

Résumé of progress in the American cement industry during 1899.

Cement Industry in the United States in 1900. Mineral Industry, Vol. IX, pp. 77–82, 1901.

Résumé of the conditions of the American Portland cement industry during 1900—a year marked by overproduction and low prices.

LEWIS, F. H., NEWBERRY, S. B., and others. *The Cement Industry.* 8vo. Pp. 235, Figs. 152. New York, 1900.

A collection of articles reprinted from issues of the Engineering Record. Detailed descriptions of a number of American cement plants, with sketches of the condition of the cement industry in various European countries; and separate chapters on the general technology of Portland cement (NEWBERRY) and the rotary kiln process (LEWIS).

MERRILL, G. P. *Guide to the Study of the Collections in the Section of of Applied Geology; the Non-metallic Minerals.* Rept. U. S. Nat. Mus. for 1899. Pp. 155–483, Pls. 1–30, 1901.

Comment.—The material contained in this handbook cannot well be summarized. The sections of interest in the present connection are those on quartz (p. 215); flint (216); limestones, mortars, and cements (pp. 264–270); dolomite (p. 274); magnesite (p. 275); feldspars (p. 281); clays (pp. 325–353); gypsum (pp. 406–411); and road-making materials (p. 482). The treatment of these subjects is, in general, excellent, that of clays being eminently so. The discussion of the cements, particularly Portland, is less satisfactory.

NEWBERRY, S. B. [*Production of*] *Portland Cement* [*in the United States during 1899*]. Twenty-first Ann. Rept. U. S. Geol. Surv., Pt. VI continued. Pp. 393–406, 1901.

Résumé of the conditlon of the American Portland cement industry during 1899, with statistics of production. The method of calculating the proportions of the ingredients in a Portland cement mixture is discussed and exemplified.

RIES, HEINRICH. *Clays of New York.* Bulletin 35, New York State Museum. 8vo, pp. 455, Pls. 140, map, 1900.

Detailed discussion of the origin, properties, testing and uses of clays, and manufacture of clay products; with descriptions of the clay deposits of New York and of the industries based on them. The section on the geologic distribution of clays in New York (pp. 275–311) is here summarized, together with the sections on shales (pp. 825–841) and feldspar and quartz (pp. 841–844).

Small deposits of residual clay, of little or no economic importance, have been found at various points in Dutchess county.

The sedimentary clays are numerous and important, representing three geologic periods — Quaternary, Tertiary and Cretaceous. The latter two occur only on Long and Staten Islands, all the clays of the mainland being Quaternary.

Local basin-shaped deposits of Quaternary clays occur at many points in the central, western and southwestern portions of the state. These deposits are doubtless on the sites of former ponds, formed commonly by the damming of valleys, and later filled with the sediment of streams from the retreating ice sheet. A number of these deposits are of economic importance, and some are now worked.

The most important and extensive clay deposits in the state, however, are those in the Hudson valley. The Quaternary deposits here are of two types (1) estuary deposits of fine stratified sand and blue and yellow clays; (2) cross-bedded delta deposits of coarser material. The clay is usually blue, weathered yellow where exposed. It is markedly stratified horizontally, the layers of clay being separated by extremely thin laminæ of sand. At many localities the clay is overlain by the delta deposits of rivers tributary to the Hudson. The Quaternary history of the region is summed up as follows: During the retreat of the ice sheet from the Hudson valley the glacial streams deposited as kames a great amount of ground up material, principally shale. Subsequent to the retreat there was a depression of the land amounting to 80 feet at New York city and 360 feet near Schenectady. During this depression a great amount of plastic clay was deposited, produced by glacial attrition of shales and limestones. The upper portion of the clay is more siliceous, and it is overlain by an extensive deposit of sand, indicating a change in the nature of the material washed into the estuary. During the period of submergence much of the siliceous matter washed into the estuary was deposited at the mouths of tributary streams to form deltas.

The clays of the Champlain valley are estuary deposits of the same age as the Hudson river clays. They underlie terraces bordering Lake Champlain, and now standing at an elevation of 393′ A. T. Extension erosion has removed much of the clays and sands, and it is only at sheltered points that the terraces are now prominent. The clays are worked for brick at Plattsburg and other localities.

Cretaceous clays occur on Staten Island, and have been worked extensively at Kreischerville and other points, the material being used in the manufacture of fire-brick, etc.

[1] "There is still some doubt as to the exact conditions under which the beds of clay and gravel which form the greater portion of Long Island were deposited, but it is probable that the clays represent shallow water marine deposits of Cretaceous and Tertiary age . . . . The age of the clays is still largely a matter of speculation, and will probably remain so in many cases unless paleontologic evidence is forthcoming. Those on Gardiner's Island are quite recent, as shown by the contained fossils, and the clay on Little Neck is Cretaceous. The proof of the age of the Glen Cove clay is not absolute . . . . The clays at Center Island, West Neck, Fresh Pond, and Fisher's Island are very similar in appearance and composition, and are very probably of the same age, possibly Tertiary, but we lack paleontologic or stratigraphic evidence. At West Neck, the clay underlies the yellow gravel and the latter is covered by the drift, so that is pre Pleistocene."

Shales occur in New York in the Hudson River, Medina, Clinton, Niagara, Salina, Hamilton, Portage and Chemung groups. Of these, the last three are the most

[1] In regard to the Long Island clays the author has been quoted verbatim, as the statements could not well be summarized.—E. C. E.

important in the present connection, though Medina shales are used in Ontario in the manufacture of pressed brick, while vitrified brick are made from Salina shales at Warners, Onondaga county, N. Y. Hamilton shales are utilized at Cairo, Greene county, in the manufacture of paving brick; and at Jewettville, Erie county, for pressed brick manufacture. Sewer pipe, drain tile and terra cotta are made from Portage shales at Angola, Erie county. Chemung shales are utilized at Jamestown, Chautauqua county; Alfred, Allegany county; Hornellsville, and Corning, Steuben county; and Horseheads, Chemung county.

Feldspar and quartz are obtained from large pegmatite veins occurring near Bedford, Westchester county, and are shipped to the potteries at Trenton, N. J.

Report on Louisiana Clay Samples. Geological Survey of Louisiana, Report for 1899. Pp. 263–275.

Discussion of origin, composition and properties of clay, followed by reports on physical tests of six samples of clay. All of the clays tested could be used in the manufacture of pressed brick, while one could also be used for paving brick and two for earthenware.

Clay and its Manufacture into Brick and Tile. Mineral Industry, Vol. IX, pp. 93–135, 12 figures, 1901.

Detailed discussion of the manufacture of building and paving brick, roofing and floor tile, terra cotta and sewer pipe.

Report on the Clays of Maryland. Special Publication, Vol. IV, Pt. III, Maryland Geological Survey. 8vo, pp. 203–507; Pls. XIX–LXIX, including six geologic maps; Figs. 5–34, 1902.

A general discussion of the origin, properties, uses and technology of clays is followed by detailed descriptions of the Maryland clays, and a résumé of the industries based on them.

According to Shattuck, the Pleistocene of Maryland is divisible into three formations; the Talbot, Wicomico, and Sunderland. The newest of these, the Talbot, does not exceed forty-five feet in thickness; and often carries lenses of greenish-black clay. The Wicomico, which is from forty-five to one hundred feet thick, seldom contains clay deposits of economic value. The Sunderland contains clay beds which are well shown in Calvert and St. Mary's counties. None of the Pleistocene clays are used for anything except common brick, though occasionally clays occur fit for tile or terra cotta.

The Neocene is represented by the Lafayette and Chesapeake formations. The Lafayette consists of gravels, sands and clays, very irregularly stratified, and changing character rapidly along the deposition planes. The Chesapeake consists chiefly of sands of marls with only local developments of clay.

Clark and Martin divide the Maryland Eocene as follows:

GROUP.	FORMATION.	MEMBER.
Pamunkey	Nanjemoy	Woodstock
		Potapaco.
	Aquia	Paspotansa
		Piscataway.

Of these four members only one, the Potapaco, contains clay deposits of importance. The Potapaco consists of argillaceous (and often gypseous) green sand, with a

lower clayey member which is shown south of South River. The clay is a fine grained material with occasional streaks of sand, and is in places twenty feet thick. It is fairly plastic, abundant, and exposed near tidewater; suitable for use in the manufacture of pressed brick and possibly of paving brick.

The Jurassic and Cretaceous of Maryland are divisible as follows:

Upper Cretaceous	Rancocas Monmouth Matawan	
Lower Cretaceous	Raritan[2] Patapsco	Potomac group.
Jurassic (?)	Arundel Patuxent.	Potomac group.

The Upper Cretaceous formations include no clay deposits of economic value; but the Potomac group is of great importance. The Raritan[1] consists usually of white sands and light colored clays, and reaches a thickness in central Maryland of one hundred[2] feet. Raritan clays are found in Cecil, Kent, Harford, Baltimore, Anne Arundel, Prince George's, Howard, and Montgomery counties. They are worked at several points for use in pressed brick manufacture; while potter's clay occurs in places. The Patapsco includes brightly colored mottled clays, with light sands and clays, and has a maximum thickness of about 200 feet. In Cecil county a bed of bluish stoneware clay often underlies the variegated clays. Refractory clays, as well as brick clays, occur, and the Patapsco clays have been exploited to a considerable extent. The Arundel contains lenses of bluish, siliceous, plastic clays, often carrying iron concretions. The clays are largely used in the manufacture of common and pressed brick, terra-cotta, roofing tile, and common pottery. The Patuxent consists largely of sands, with occasional beds of sandy clay, and is, in this regard, the least important member of the Potomac.

Shales from the different formations of the Carboniferous, Devonian and Silurian have been tested and found suitable for various uses. At present only two of these formations furnish material of economic importance, these being the Pottsville formation of the Carboniferous and the Jennings formation of the Devonian. Both flint clays and plastic clays occur in the Pottsville formation, the well-known Mt. Savage fire clay being an example of the former. The beds have been opened near Frostburg, at Mt. Savage and west of Ellerslie; and will probably become of even greater economic importance. Shales of the Jennings formation are extensively used in the manufacture of paving brick at Cumberland.

Kaolin occurs at many points in the area underlain by Algonkian rocks, notably in Cecil county. These residual clays, having been derived from feldspathic rocks low in iron-bearing minerals, are light colored and burn white. Only one company is actually at work mining and washing this material, but the industry will probably increase rapidly in importance. Owing to the presence of Patuxent and Columbia beds, the kaolin is rarely exposed at the surface, the necessary stripping varying from two to forty feet.

[1] On page 397 the Raritan is excluded from the Potomac, but is included in it on pages 399 *et seq.*—E. C. E.

[2] Elsewhere in the volume stated as 500 feet.—E. C. E.

Less-pure residual clays, derived from rocks of various kinds and ages, are found at many points in the state, and are used in places for brick manufacture.

SIEBENTHAL, C. E. *The Silver Creek Hydraulic Limestone of Southeastern Indiana.* Twenty-fifth Ann. Rept. Indiana Dept. Geology and Natural Resources Pp. 331–389, Pl. 14, colored geologic map, 1901.

Divided into three sections relating respectively to the stratigraphy, topography and economic geology of the Silver Creek limestones.

A historical résumé of opinions in regard to the stratigraphy of southeastern Indiana is followed by descriptions of local distribution and structure. The Devonian and sub-Carboniferous formations occurring in this area, with their New York and Mississippian (paleontologic) equivalents, are:

Sub-Carboniferous	Knobstone	Kinderhook.
	Rockford limestone	Choteau.
Devonian	New Albany black shale	Genesee.
	Sellersburg limestone	Hamilton.
	Silver Creek hydraulic limestone	Hamilton.
	Jeffersonville limestone	Corniferous.
	Pendleton sandstone	Schoharie.

The topography is briefly mentioned. Pleistocene terraces are described and mapped, and a possible preglacial channel of the Ohio River is pointed out.

The Silver Creek hydraulic limestone is massive, very fine grained and usually fossiliferous. In color it varies from light to dark or bluish-drab, weathering buff. In composition it varies between the following limits: Calcium carbonate 52 per cent. to 62 per cent.; magnesium carbonate 16 per cent. to 35 per cent.; silica 9.5 per cent. to 18.5 per cent.; ferric oxide 1.4 per cent. to 2.0 per cent.; alumina 2 to 5 per cent. The cement rock is obtained by quarrying or mining, according to the situation; blasted out by dynamite and sledged to proper size (6"–12") for the kilns. The latter are continuous up-draft kilns, and require about seventy-two hours for calcination. The burned rock is sent through crushers, "re-grinders," and rock-emery mills. During 1900, thirteen plants, working 116 kilns, were in operation, the total product being 2,512,000 barrels.

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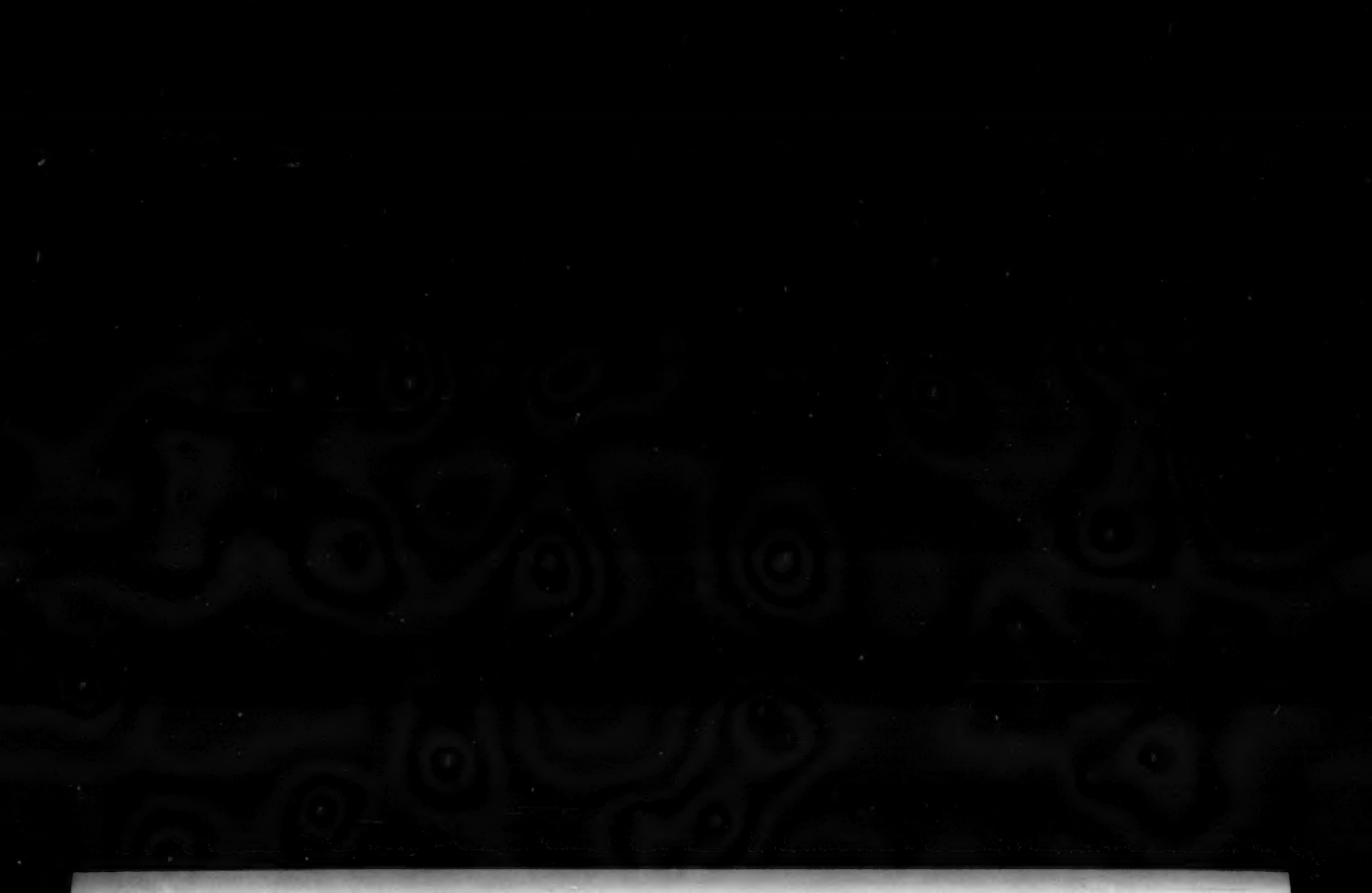
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